

Investigating the Effects of Bimanual Multitouch Interaction on Creativity

by

Allen Bevans

B.F.A, University of Lethbridge, 2008

*THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF*

MASTER OF SCIENCE

In the

School of Interactive Arts + Technology
Faculty of Communication, Art and Technology

©Allen Bevans 2011

SIMON FRASER UNIVERSITY

Summer 2011

All rights reserved. However, in accordance with the *Copyright Act of Canada*, this work may be reproduced, without authorization, under conditions for *Fair Dealing*. Therefore, limited reproduction of this work for the purposes of private study, research, criticism, review, and new reporting is likely to be in accordance with the law, particularly if cited appropriately.

APPROVAL

Name: Allen Bevans
Degree: Master of Science
Title of Thesis: Investigating the Effects of Bimanual Multitouch Interaction on Creativity

Examining Committee:
Chair:

Dr. Marek Hatala
Associate Professor, School of Interactive Arts + Technology

Dr. Alissa N. Antle
Senior Supervisor
Assistant Professor, School of Interactive Arts + Technology

Dr. Thecla Schiphorst
Supervisor
Associate Professor, School of Interactive Arts + Technology

Dr. Andra Smith
External Examiner
Assistant Professor, School of Psychology
University of Ottawa

Date Defended/Approved: Augst 12, 2011



SIMON FRASER UNIVERSITY
LIBRARY

Declaration of Partial Copyright Licence

The author, whose copyright is declared on the title page of this work, has granted to Simon Fraser University the right to lend this thesis, project or extended essay to users of the Simon Fraser University Library, and to make partial or single copies only for such users or in response to a request from the library of any other university, or other educational institution, on its own behalf or for one of its users.

The author has further granted permission to Simon Fraser University to keep or make a digital copy for use in its circulating collection (currently available to the public at the "Institutional Repository" link of the SFU Library website <www.lib.sfu.ca> at: <<http://ir.lib.sfu.ca/handle/1892/112>>) and, without changing the content, to translate the thesis/project or extended essays, if technically possible, to any medium or format for the purpose of preservation of the digital work.

The author has further agreed that permission for multiple copying of this work for scholarly purposes may be granted by either the author or the Dean of Graduate Studies.

It is understood that copying or publication of this work for financial gain shall not be allowed without the author's written permission.

Permission for public performance, or limited permission for private scholarly use, of any multimedia materials forming part of this work, may have been granted by the author. This information may be found on the separately catalogued multimedia material and in the signed Partial Copyright Licence.

While licensing SFU to permit the above uses, the author retains copyright in the thesis, project or extended essays, including the right to change the work for subsequent purposes, including editing and publishing the work in whole or in part, and licensing other parties, as the author may desire.

The original Partial Copyright Licence attesting to these terms, and signed by this author, may be found in the original bound copy of this work, retained in the Simon Fraser University Archive.

Simon Fraser University Library
Burnaby, BC, Canada

STATEMENT OF ETHICS APPROVAL

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

(a) Human research ethics approval from the Simon Fraser University Office of Research Ethics,

or

(b) Advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University;

or has conducted the research

(c) as a co-investigator, collaborator or research assistant in a research project approved in advance,

or

(d) as a member of a course approved in advance for minimal risk human research, by the Office of Research Ethics.

A copy of the approval letter has been filed at the Theses Office of the University Library at the time of submission of this thesis or project.

The original application for approval and letter of approval are filed with the relevant offices. Inquiries may be directed to those authorities.

Simon Fraser University Library
Simon Fraser University
Burnaby, BC, Canada

ABSTRACT

This thesis presents the results of an exploratory comparative study investigating the potential effects of bimanual interaction on creativity. Recent research from cognitive psychology and neuroscience suggests that body movement influences divergent thinking performance in previously unexpected ways. Divergent thinking is the process of generating multiple valid responses to a situation, and is an important part of creative behaviour. To examine the impact of the body movements afforded by multitouch displays on divergent thinking, study participants interacted with a computerized version of the Alternate Uses Task, a divergent thinking measurement test. Participants were assigned to one of three different interface styles: mouse, unimanual multitouch, and bimanual multitouch. In order to evaluate differences in creative performance between the interface styles, participant responses from the AUT were scored along several subscales, transforming qualitative AUT response data into quantitative data suitable for statistical analysis. While no strong interface style effects on divergent thinking were found, important findings about language ability and representational modality were identified. The summary of this analysis and implications for the design of creativity-support systems are discussed herein.

The main contribution of this study is that it is the first empirical comparison of multitouch interaction and traditional mouse-based interaction focusing on creative performance. A second contribution is a unique combination of current research and methodological approaches from psychology, neuroscience and HCI. A third contribution is the development of a computerized version of the Alternate Uses Task, capable of being run on diverse interaction platforms.

Keywords: Interface style, input methods, multitouch, bimanual, direct, indirect, comparative studies, divergent thinking, creativity.

DEDICATION

For my parents, who taught me to work hard, think harder, and never give up.

ACKNOWLEDGEMENTS

First, a superlative thank-you full of gratitude to Alissa Antle for guiding my studies and this research here at SIAT. I have been stretched beyond what I believed were my limits, and you have consistently provided support, warmth, and a voice of reason. Working under your tutelage as an educator, researcher, designer, academic, and all-around excellent human had made me a better person in innumerable ways.

To Thecla Schiphorst for my very first class as a graduate student (hooray for art as research!) and for your unflagging cheer and enthusiasm for my work. I always think of you, your research, and our conversations when I get mired in the inanities of rigidly-quantitative thinking.

To Dr. Andra Smith for volunteering your time and brainpower to evaluate this thesis. Agreeing to be involved with slightly bizarre HCI research from halfway across the country shows incredible trust and commitment to the highest of academic ideals.

To SSHRC for generous funding and continued support.

To Andrew Haw for a roof over my head when I needed it, and for timely sanity-checks. Let's just hope these new-fangled Master's thingies work out for us, eh?

To Josh and Karen Tanenbaum for guidance, confidence, friendship, empathy, compassion, and alcohol. The world is a much more magical place with folks like you in it.

To Andres Wanner for fun times teaching and even funner times marking.

To Diego, Anna, Ying, Andrew M, Jack, Vero, Ben, and the rest of my colleagues at SIAT for smiles, encouragement, and camaraderie.

Finally, to Jo for your endless well of love and support. Where have you been all my life?

TABLE OF CONTENTS

APPROVAL	ii
ABSTRACT.....	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS.....	vi
LIST OF FIGURES.....	ix
LIST OF TABLES.....	ix
GLOSSARY.....	x
CHAPTER 1: INTRODUCTION	1
1.1 Overview	1
1.2 Research Goals.....	5
1.3 Thesis Guide	5
CHAPTER 2: THEORETICAL BACKGROUND.....	7
2.1 Overview	7
2.2 Bimanual Computer Interaction.....	8
2.3 Direct vs Indirect interaction.....	17
2.4 The Cognition of Creativity.....	20
2.5 Human Creativity and Divergent Thinking.....	21
2.5.1 Divergent Thinking and Inter-Hemispheric Interaction.....	22
2.5.2 Other Physiological Influences on Inter-Hemispheric Interaction	23
2.6 The Alternate Uses Task.....	24
2.6.1 The Alternate Uses Subscales	25
2.7 Human Computer Interaction and Creativity.....	26
2.8 Research Questions.....	27
CHAPTER 3: EXPERIMENTAL DESIGN – FRAMEWORK.....	29
3.1 Overview	29
3.2 Hypotheses.....	30
3.2.1 Hypothesis One	30
3.2.2 Hypothesis Two.....	31
3.2.3 Hypothesis Three.....	31
3.2.4 Hypothesis Four	32
3.2.5 Hypothesis Five	32
3.3 Demographic Variables.....	33
3.4 Independent Variables	33
3.5 The Computerized Alternate Uses Task	34
3.5.1 The Procedure.....	38
3.5.2 Dependant Variables	38
3.6 Demographic Measures – English fluency and Handedness.....	39
CHAPTER 4: EXPERIMENTAL DESIGN – METHODOLOGY.....	41

4.1	Overview	41
4.2	Participants	41
4.3	Setting	43
4.4	Assumptions	43
4.5	Pilot Study	45
4.6	Experimental Procedure	45
4.7	Scoring the Alternate Uses Task.....	47
4.8	Scoring with an external rater	48
4.8.1	Inter-rater reliability	49
4.9	Scoring originality	49
4.10	Preparing scores for analysis	51
4.11	Statistical Analysis Method – Handedness and English Fluency.....	51
4.12	Statistical Analysis – Alternate Uses Subscales.....	54
4.12.1	Normalcy and homogeneity of variance.....	54
4.12.2	Appropriate statistical comparisons	57
4.13	Qualitative Observations.....	59
CHAPTER 5: RESULTS		60
5.1	Overview	60
5.2	Results for Hypotheses	60
5.2.1	Hypothesis One: Flexibility and Originality within Mouse and Unimanual Multitouch	60
5.2.2	Hypothesis Two: Flexibility and Originality for Strong-Handed Participants by Interface Style	62
5.2.3	Hypothesis Three: Flexibility and Originality for Bimanual Multitouch participants by Handedness	63
5.2.4	Hypothesis Four: All AUT subscales for Mouse and Unimanual Multitouch by Handedness.....	64
5.2.5	Hypothesis Five: Fluency, Appropriateness and Detail within Mouse and Unimanual Multitouch by Interface Style	67
5.3	Demographic Variables.....	69
5.3.1	Gender	69
5.3.2	Age.....	70
5.3.3	Language Background	72
5.3.4	Interface and Computer Experience.....	74
5.4	Qualitative Observations.....	75
CHAPTER SIX: DISCUSSION.....		76
6.1	Overview	76
6.2	Discussion of Research Questions	76
6.2.1	Boosting Flexibility and Originality for Strong-handed participants through bimanual interaction Does bimanual interaction affect divergent thinking in a similar way to bilateral eye movement?	76
6.2.2	Higher AUT performance for Mixed-hand participants compared to Strong-hand when using unimanual interfaces Do mixed-handed users interacting with one-handed interfaces maintain greater divergent-thinking ability than strong-handed users with these interfaces?.....	78
6.2.3	Divergent thinking changes affected by Direct vs. Indirect interaction Are there differences between direct and indirect interaction that affect divergent thinking performance?	79
6.3	Demographic variables affecting divergent thinking: Age and Language.....	79
6.4	Object Representation and Divergent Thinking Strategies	81
6.5	Bilateral Eye Movement and Human-Computer Interaction	82
6.6	Design Implications	83

CHAPTER SEVEN: CONCLUSION.....	84
7.1 Overview	84
7.2 Summary of Findings.....	85
7.3 Limitations.....	85
7.4 Future Research	86
Appendices	88
Appendix A: List of Alternate Use Task objects, including typical uses	89
Appendix B: Post-session Questionnaire, including Edinburgh Handedness Inventory	90
Appendix C: Expedited Approval of Ethics Application	92
Reference List	93

LIST OF FIGURES

Figure 2.1 – The two-handed tangible interface for neurosurgical planning from Hinckley et al (1998)...	11
Figure 2.2 – Target object (left) and tool (right) from Hinckley et al (1998)	12
Figure 2.3 – Screen shots from the bimanual alignment task used by Hinckley et al (1998).....	13
Figure 3.1 – Mappings of functions to interface styles for the computerized AUT.....	34
Figure 3.2 – Screenshot of computerized AUT displaying an object for the mouse interface	35
Figure 3.3 – Screenshot of computerized AUT displaying an object for the bimanual interface	35
Figure 3.4 – 3d models of AUT objects created for the computerized AUT	36
Figure 3.5 – Promotional photo of the 3M M2256PW 22” capacitive multitouch display	38
Figure 4.1 – Scatterplot of face fluency by FAS fluency score	52
Figure 4.2 – FAS Score by AUT fluency with Face Fluency group indicated	53
Figure 5.1 – AUT subscales by gender	70
Figure 5.2 – AUT subscales by age group.....	71
Figure 5.3 – AUT subscales by self-report as a native English speaker.....	72

LIST OF TABLES

Table 4.1 – Shapiro-Wilk tests for normalcy by interface style	54
Table 4.2 – Shapiro-Wilk tests for normalcy by interface style	54
Table 4.3 – Shapiro-Wilk tests for normalcy by hand group	55
Table 4.4 – Shapiro-Wilk tests for normalcy by hand group	55
Table 4.5 – Shapiro-Wilk tests for normalcy by hand group	56
Table 4.6 – Levene's test on <i>originality</i> variance between hand groups within participants assigned to the bimanual interface.....	57
Table 5.1 – Comparisons between mixed and strong-handed participants using unilateral interfaces for each AUT subscale	65
Table 5.2 – Comparisons between mixed and strong-handed participants using the mouse interface for each AUT subscale	66
Table 5.3 – Comparisons between mixed and strong-handed participants using the unimanual multitouch interface for each AUT subscale.....	66
Table 5.4 – Age group distribution	71
Table 5.5 – Results of mean rank analysis for AUT subscales by native English speaking background	73
Table 5.6 – Results of Man-Whitney U for AUT subscales by native English speaking background	73
Table 5.7 – Spearman's ρ for face fluency, native English speaking background, and FAS score	74

GLOSSARY

Unimanual	One-handed. In the context of interaction with a computer, unimanual interaction involves interacting through the interface with a single hand.
Bimanual interaction	Two-handed. In the context of interaction with a computer, bimanual interaction involves interacting through the interface using both hands.
Direct interaction	“Hands-on-screen” interaction. Interaction with a computer where the hand is spatially co-located with the visual output display. Typically supported by various forms of touch screen technology.
Indirect interaction	“Hands-off-screen” interaction. Interaction with a computer where the hand is spatially separated from the visual output display. Typically supported by external controllers such as mice and keyboards.
Divergent thinking	The mental process of generating multiple solutions to a problem or situation. Divergent thinking is considered to be an important aspect of most creative behaviour, and is often studied as a creativity construct.
Bilateral eye movement (BEM)	An exercise which involves moving the eyes back and forth horizontally deliberately in sync. More generally, it is a specific example of a bilateral body movement (a body movement performed on both sides of the body).
Inter-hemispheric interaction (IHI)	Activity in the corpus callosum (the connective tissue between brain hemispheres) which coordinates interaction between specific brain regions on different sides of the brain.
Alternate Uses Task (AUT)	A divergent thinking assessment tool wherein participants are asked to generate new uses for everyday objects. These uses are then evaluated to compare divergent thinking ability between individuals and groups.
Handedness	A reference to an individual’s hand-use preference, usually described in terms of dominant and non-dominant hand. Individuals who switch between their right and left hands for dominant-hand tasks (writing, throwing, etc.) are considered mixed-handed, while individuals who consistently use a specific hand for dominant-hand tasks are considered strong-handed.

CHAPTER 1: INTRODUCTION

1.1 Overview

The growing prevalence of commercial and do-it-yourself multitouch hardware such as the Apple iPad and Microsoft Surface has brought with it a corresponding increase in multitouch interface research and prototyping. In response, interest in HCI research dealing with gestural interaction, collaborative computing, and bimanual interaction has increased. Large multitouch surfaces and walls offer the potential of rich bimanual input, and interface designers and researchers have just begun to explore the advantages, pitfalls, and best practices of leveraging this technology for two-handed use.

Fortunately, HCI researchers interested in bimanual interaction have a large body of previous research to draw upon. This research has usually been done in the context of technology-driven trends. For example, the widespread adoption of continuous controllers like the mouse in the mid 1980's as well as virtual reality research in the mid 1990's brought with them surges in bimanual interaction research associated with the input capabilities afforded by these technologies. Many of the findings from these periods of previous bimanual research can be applied beyond their technical domain to contemporary bimanual multitouch research and other HCI areas. While a small but significant portion of this research has examined the influence of bimanual interaction on how people think when using these interfaces (i.e. differences in users' cognition), the majority of this research has focused on the bio-mechanical advantages that two-handed interaction affords.

Among the research that has investigated the influence of bimanual interaction on cognition two general classes of advantages have been theorized. First, that bimanual interaction alters the mental model used to approach a task (Hinckley, Pausch, Proffitt, Patten, & N. Kassell, 1997) and second, that an interface designed for bimanual interaction may afford the offloading of memory and cognitive effort

onto the interface in ways not supported by unimanual interfaces (Leganchuk, Zhai, & W. Buxton, 1998; Owen, Kurtenbach, Fitzmaurice, Baudel, & B. Buxton, 2005). Researchers have also noted that many human capabilities predict certain bimanual advantages, such as our keen awareness of the position of our hands in space without visual observation (kinaesthesia/proprioception) (Hinckley et al., 1997). While there is empirical evidence that supports these theories of bimanual advantage, these advantages are usually highly dependent on the specific design of a bimanual interface prototype. In fact, researchers have noted that improperly designed bimanual interfaces have the potential to negatively affect time-motion efficiency and other bio-mechanical measures (Kabbash, W. Buxton, & Sellen, 1994; Balakrishnan & Hinckley, 2000). Ultimately, despite decades of research in a variety of technological contexts, no widely-generalizable bimanual interaction advantages have been observed.

Besides bimanual interaction research, contemporary multitouch research is informed by research in direct and indirect interaction. In earlier decades the terms “direct” and “indirect” interaction referred to software design paradigms – direct interfaces were defined as interfaces that let users directly manipulate graphical objects representing data or processes, as opposed to indirect text-based command line interaction (Shneiderman, 1982). Recently, however, direct/indirect interaction has referred to the physical coupling of input and output spaces (Sears & Shneiderman, 1991; Forlines & Balakrishnan, 2008). By this usage of the terms a “direct” interface is an interface like a touch screen, which receives input from user’s fingers while simultaneously displaying the system’s output in the same physical space as the user’s fingers. An “indirect” interface is defined as an interface where user input is separated from the physical output space of the system, such as a mouse controlling a cursor on-screen. While research has shown that direct and indirect interaction affect basic task performance for some selection tasks (Kin, Agrawala, & DeRose, 2009), the effects of direct versus indirect interaction on user cognition remain largely unexplored empirically.

One area of human cognition that shows promise for enhancement via bimanual interaction is creativity. Creativity has long been an active area of psychological and neurological research (Torrance, Glover, Ronning, & Reynolds, 1989; T. M. Amabile, 1982; T. Amabile, 1996; Plucker & Runco, 1998a; Sternberg, 1999; Fink & Neubauer, 2006). This research base provides a rich and diverse foundation for creativity related HCI research. In particular, a growing understanding of low-level neural processes involved in creative behaviour coupled with a diverse history of empirical creative assessment approaches suggests that detailed examinations of creative performance during human-computer interaction is possible.

One specific area of current creativity research in psychology and neuroscience concerns the role of inter-hemispheric interaction (IHI) during creative thought. IHI describes activity in the corpus callosum, which is the connective tissue between brain hemispheres. IHI coordinates activity between specific brain regions on different sides of the brain. Recent work examining IHI during divergent thinking (an important component of creativity) has shown that creativity can be manipulated by performing bilateral body movements such as bilateral eye movements (Shobe, Ross, & Fleck, 2009). Experimental tasks designed to measure various divergent thinking constructs have been shown to correlate with “real-world” creativity (Torrance, 1981; Sternberg, 1988; Heilman, Nadeau, & Beversdorf, 2003).

Research has also shown that divergent thinking is an important aspect of creativity in a wide variety of areas, from art, engineering and design to market innovation (Cropley & Cropley, 2000; Dahl & Moreau, 2002; Gibson, Folley, & Park, 2009).

The creative process of divergent thinking is defined as ideation-driven cognition in response to a given situation. The goal of divergent thinking is to generate many potential solutions to a single situation. For example, when presented with a common everyday object, the process of coming up with new uses for the object is considered as divergent thinking. This is in contrast to convergent thinking, which is the

type of thinking used to solve problems with a single correct solution. New-use ideation tasks form the basis for the widely used Alternate Uses Task (AUT), a divergent thinking assessment technique (Christensen, Guilford, Merrifield, & Wilson, 1960; Guilford, 1967) involving the generation of new uses for everyday objects. Throughout extensive and varied use in creativity research the AUT has been shown to reliably measure various aspects of divergent thinking such as ideational fluency, flexibility, and originality (Dyne & Saavedra, 1996; Wyver & Spence, 1999; Ames & Runco, 2005; Fink, Benedek, Grabner, Staudt, & Neubauer, 2007), although there is some debate about how best to evaluate AUT performance (Mouchiroud & Lubart, 2001; Plucker & Runco, 1998b; Silvia, Martin, & Nusbaum, 2009; Silvia et al., 2008). Creativity researchers have also acknowledged that although there is an extensive body of research examining divergent thinking via content-general tasks such as the AUT, a more complete evaluation of creativity must include domain-specific evaluations (T. Amabile, 1996; Pretz & Link, 2008) and research into other components of creative behaviour such as convergent thinking (Runco, 1991; Mouchiroud & Lubart, 2001; Dietrich & Kanso, 2010).

In this thesis, I build on recent research such as Shobe, Ross, & Fleck's Bilateral Eye Movement study (Shobe et al., 2009) and the rich body of creativity research in psychology and neuroscience in order to examine the effects of bimanual human-computer interaction on cognition – specifically divergent thinking. My research is the first known empirical assessment of the effects of bimanual interaction on divergent thinking. I conducted an experimental comparison of how bimanual and unimanual human-computer interaction affects divergent thinking as measured by the AUT. This thesis chronicles this research.

1.2 Research Goals

The research documented herein addresses the following questions:

- Does bimanual interaction on large multitouch displays affect divergent thinking in a similar way to bilateral eye movement?
- Do mixed-handed users performing one-handed interaction maintain greater divergent-thinking ability than strong-handed users with these interfaces?
- Are there differences between direct and indirect interaction that affect divergent thinking performance?
- If divergent thinking increases when using bimanual multitouch interfaces, what are some key design considerations for supporting this increase in interface design?

The specifics and results of how these questions have been addressed through my thesis research, as well as a review of important related research, constitutes the remainder of this document.

1.3 Thesis Guide

The chapter you are currently reading (Chapter One) serves as an introduction to my thesis work.

Hopefully you will continue into Chapter Two, which includes a literature review of foundational and related research in HCI, psychology, and neuroscience that informs this thesis. Chapter Three consists of an in-depth discussion of my hypotheses, experimental design, and assessment framework including a task description. Chapter Four involves a review of the my experimental methodology, including: experimental apparatus setup, results of pilot studies, resulting changes to experimental design, recruitment of experiment participants, and a discussion of data collection and statistical approaches for data analysis. Chapter Five presents the quantitative analysis and results of divergent thinking assessment and a summary of qualitative observations based on notes taken during the experiment.

Chapter Six contains interpretations of Chapter Five's quantitative and qualitative analyses, including a discussion of the implications of these results on bimanual interface design. Finally, Chapter Seven sums up the findings, contributions, and limitations of this research, and provides suggestions for future research. Appendices and a list of references are included in order to provide a detailed record of my research and complete the thesis experience.

CHAPTER 2: THEORETICAL BACKGROUND

2.1 Overview

This study was inspired by the emergence of DIY and consumer-targeted multitouch displays, such as Jeff Han's low-cost FTIR multitouch display (Han, 2005) and the Microsoft Surface ("Welcome to Surface," <http://www.microsoft.com/surface/>). Early software demonstrations on these systems hinted at the potential of large multitouch displays for multi-user interaction, direct interaction with rich virtual objects, and expressive gestural control. Beyond isolated academic and industry-specific niche products, however, much of the promised potential of large multitouch displays has yet to be realized. A "killer app" that encapsulates these potentials in a compelling and widely-applicable application has not yet emerged. It is worth noting that this is not the case with *small* multitouch displays, such as the touch-screens that have become the input standard on smart phones. However, these portable multitouch displays do not afford the same potential for multi-user interaction and expressive gestural control that large multitouch displays afford. The recent emergence of seven to ten inch tablets is a start at bridging the gap between small and large multitouch displays. Prompted by the rich human and computer interaction potential of large multitouch displays, I have focused my master's research on empirically investigating how humans use these interfaces in ways which differentiate them from traditional (e.g. mouse and keyboard) interfaces and which may be applied to a broad range of applications.

As briefly discussed in the previous chapter, I have chosen an investigation of the potential effects of bimanual interaction as afforded by large multitouch displays on creative thinking. I acknowledge that the leap from "I want to find out what multitouch is good at" to "let's see how using two hands on multitouch displays affects creativity" is not immediately clear and straightforward. This chapter is intended to outline and clarify how my research efforts arrived here from such vague beginnings. Because large multitouch displays afford a diverse selection of unique interaction capabilities from a

research perspective, I had to delineate one specific aspect of multitouch interaction to focus my research on. I chose the affordance of expressive two-handed (or bimanual) interaction that large multitouch makes possible. This choice is partly due to a lingering interest in gestural mark-making in computer interfaces involving whole-arm motion from my undergraduate education in new media, and partly due to recent findings from cognitive psychology linking body movement to specific cognitive changes which will be discussed later in the chapter. In this chapter I review applicable research literature from human-computer interaction and link this research to related research from psychology and cognitive neuroscience in order to clarify the motivation of my thesis research.

2.2 Bimanual Computer Interaction

Bimanual interaction has long been a subject of research in the HCI community, as bimanual computer interaction technologies in various forms have existed for quite some time. One of the earliest exploratory HCI studies specifically investigating bimanual input is “A study in two-handed input” (Buxton & Myers, 1986). The authors found that both expert and novice users of two custom puck-and-slider bimanual interfaces had decreased task time on a task that involved figure positioning and scaling and a second task that involved document scrolling and selecting. This research laid groundwork for several themes that appear in the bulk of HCI research into bimanual interfaces since. First, it frames the advantage of bimanual interaction over unimanual interaction primarily as an increase in biomechanical efficiency – users are able to complete multiple actions more efficiently by offloading different actions to each hand, increasing their overall time-motion efficiency (Kin et al., 2009). Second, it characterizes user interaction as *parallel* or *serial* interactions: *parallel* bimanual interaction involves each hand performing action simultaneously in the completion of the task, while *serial* bimanual interaction involves “turn-taking” between each hand as the task is completed. Interestingly, Buxton and Myers found that even when users used a *serial* bimanual approach during the scrolling and selecting task, they had quicker task completion times than participants using unimanual interfaces.

Beyond considerations of *parallel* and *serial* hand use, later HCI research into bimanual interaction also began to make use of the research of Yves Guiard's theoretical Kinematic Chain model of hand use (Guiard, 1987). The Kinematic Chain model compares cooperative bimanual hand movement to a series of linked motors. According to the model, the non-dominant hand (e.g. the left hand for right-handed individuals) sets the frame of reference for a bimanual task via gross movements while the dominant hand carries out task operations through finer motions within that frame. The classic example of this type of hand use is writing on a piece of paper: the non-dominant hand sets and moves the gross position of the page, while the dominant hand writes on the page via smaller refined motions.

Adoption of this model by HCI researchers prompted the acceptance of two additional terms to describe bimanual interaction tasks: *symmetrical* and *asymmetrical*. *Symmetrical* bimanual movement describes the case when both hands have the same role in a task. *Asymmetrical* bimanual movement describes the case when each hand is assigned to a different (but typically complementary) role in completing the task (Balakrishnan & Hinckley, 2000). For example, both of Buxton and Myers' tasks would be considered *asymmetrical* interaction tasks, with the non-dominant hand controlling the sliders in each task, and the more "precise" dominant hand controlling the puck. Many HCI researchers have leveraged Guiard's theory in designing bimanual interfaces which asymmetrically assign tasks to each hand, including the Toolglass and Magic Lens interfaces (Bier, Stone, Pier, W. Buxton, & T. D. DeRose, 1993), two-pointer 3d input (Zelevnik, Forsberg, & Strauss, 1997), and the ubiquitous Parameter and Command interaction approach (most commonly implemented as hotkeys + mouse, according to Odell, Davis, Smith, & Wright, 2004). Several HCI researchers have sought to explicitly confirm the Kinematic Chain theory in computer interaction contexts (Balakrishnan & Hinckley, 1999; Xia, Irani, & Wang, 2007), and numerous HCI researchers have also used Guiard's theory as an explanatory model for observed interaction behaviours without explicitly basing the design of their interfaces on the Kinematic Chain

(Kabbash, W. Buxton, et al., 1994; Hinckley, Pausch, Proffitt, & N. F. Kassell, 1998; Balakrishnan & Kurtenbach, 1999; Latulipe, Kaplan, & Clarke, 2005).

Discussion and application of Guiard's Kinematic Chain theory by HCI researchers is typically framed in terms of users' "natural" hand use. With a formal description of how humans use their hands together in "real-world" tasks, interface designers and evaluators can assess an interface's match to user's expectations and proficiencies. This implies that bimanual interfaces which support the hand roles and relationships suggested by Guiard provide some physical and cognitive advantages over bimanual interfaces which do not. In other words, Guiard describes a "proper" or "common" structure to bimanual hand use which HCI researchers use to identify and improve bimanual interfaces which do not leverage this hand-use structure. Some HCI researcher's have even attempted to measure the advantage of Guiard's Kinematic Chain model when applied to interface design in terms of accuracy and efficiency (Xia et al., 2007). Many HCI researchers who cite Guiard tend to focus on the physical advantages of bimanual interfaces while implicitly attributing a cognitive advantage to bimanual interaction. Additionally, some HCI researchers have explicitly investigated the cognitive effects of bimanual interaction as well as potential cognitive advantages bimanual interaction may afford when specifically compared to one-handed (unimanual) interaction.

A prominent research project from HCI research which considers the cognitive changes bimanual interaction introduces is Hinckley and colleagues' research with a two-handed tangible interface for neurosurgical planning (Hinckley et al., 1997, 1998). The interface they studied consists of a plastic doll's head held in one hand and a planar controller held in the other. These interactive objects are used together to explore a 3d model of brain-scan imagery and define a detailed cross-section view by translating and rotating the 3d model (linked to rotation and position of the doll's head) and a slice plane (linked to the planar controller).

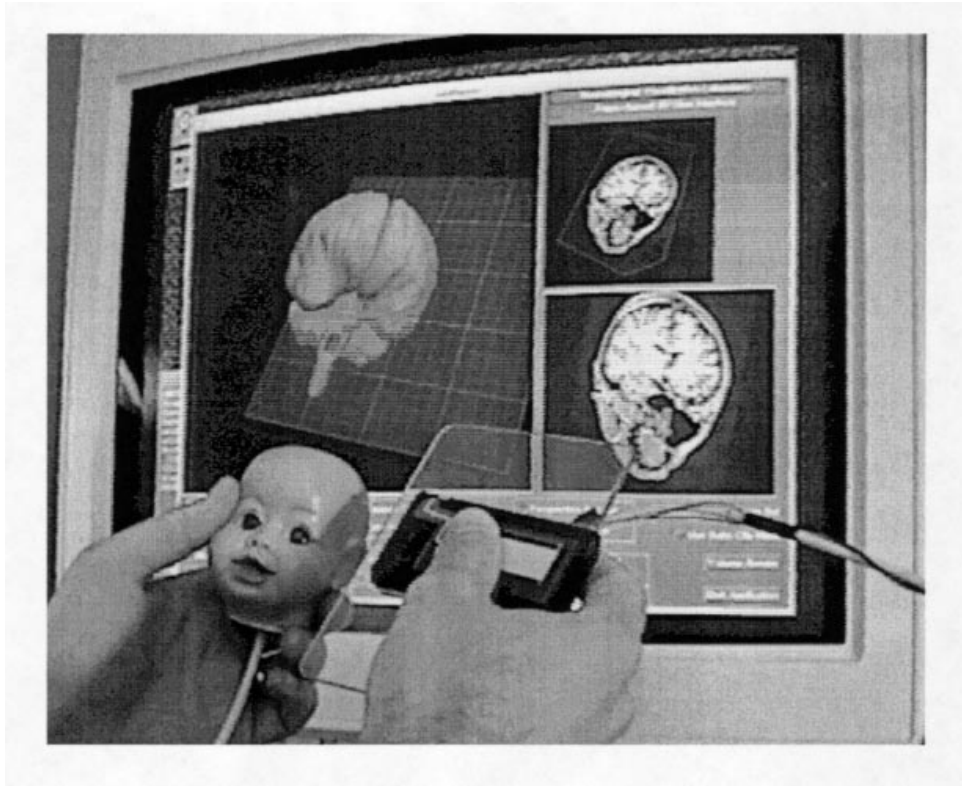


Figure 2.1 – The two-handed tangible interface for neurosurgical planning studied by Hinckley et al (1998).

Hinckley and colleagues sought to ground their work in contemporary psychological research (including Guiard’s Kinematic Chain theory) and so undertook empirical testing of the interface to verify design goals. It was also their intent to challenge design assumptions of the interface via the application and interpretation of theoretical descriptions of hand use and cognition.

In a preliminary experiment examining hand role and bimanual accuracy Hinckley and colleagues asked participants to touch a tool held in one hand to a target portion of an object held in the other hand. Participants were asked to complete an “easy” version of the task where the target spot on the object was large and a “hard” version where the target was marginally larger than the tool held in the other hand.

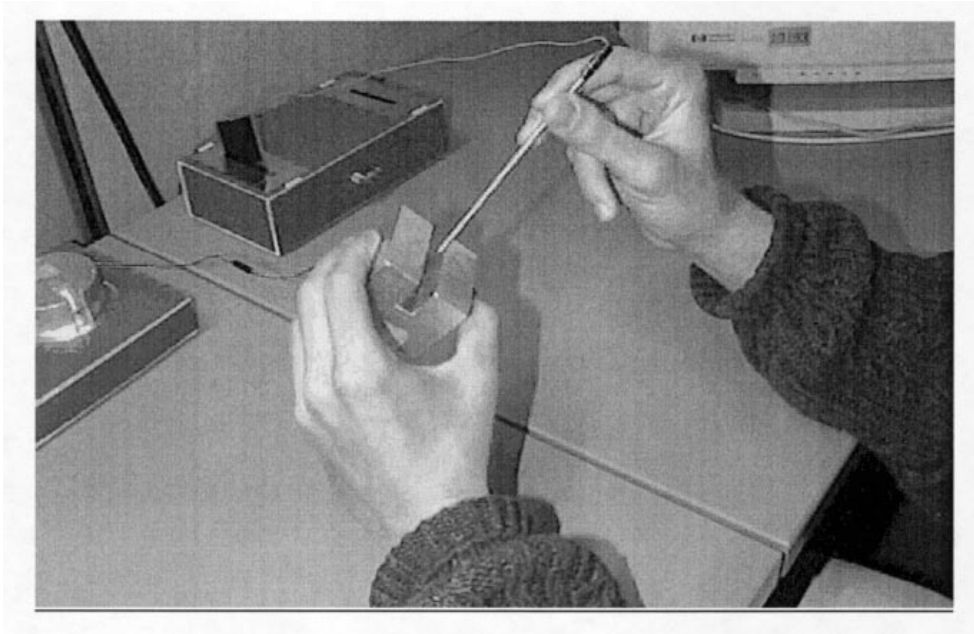


Figure 2.2 – Target object (left) and tool (right) from Hinckley et al (1998).

Participants were required to complete each task several times with the tool in their dominant hand and target object in their non-dominant hand, and again with the hands switched (tool in non-dominant hand, target in dominant hand). The researchers recorded task completion time and number of errors (missing the target) while attempting to complete the task. Specialization of hand roles only affected performance in the “hard” task (increased errors and completion time for successful runs were observed), while the “easy” condition of their experiment did not show significant performance differences when hand roles were switched. They also observed that when the non-dominant hand was used to hold the tool during the “hard” condition some participants still attempted to use the non-dominant hand as a frame of reference while holding the tool still and moving the target object with towards the tool, as opposed to manipulating the tool towards the target with their non-dominant hand. Hinckley et al also observed that during the “easy” task participants used an “almost symmetric” approach to touching the tool to the target. While these findings suggest a possible cognitive aspect to bimanual hand use (e.g. shifting bimanual strategies as task difficulty changes, taking longer to complete

the harder task accurately), it could be argued that the findings simply confirm that participants were more practiced with fine motor control of their dominant hands, leading to more accurate and timely movements when they controlled the position of the tool with their dominant hand.

Hinckley et al carried out a second experiment involving the two-handed tangible neurological planning interface which examined the roles of vision and proprioception in bimanual memory. Participants were asked to use the interface to align the angle of a plane with a screen-displayed virtual object. The task plane was controlled by the planar controller held in the dominant hand and the virtual object was controlled by the doll's head held in the non-dominant hand.

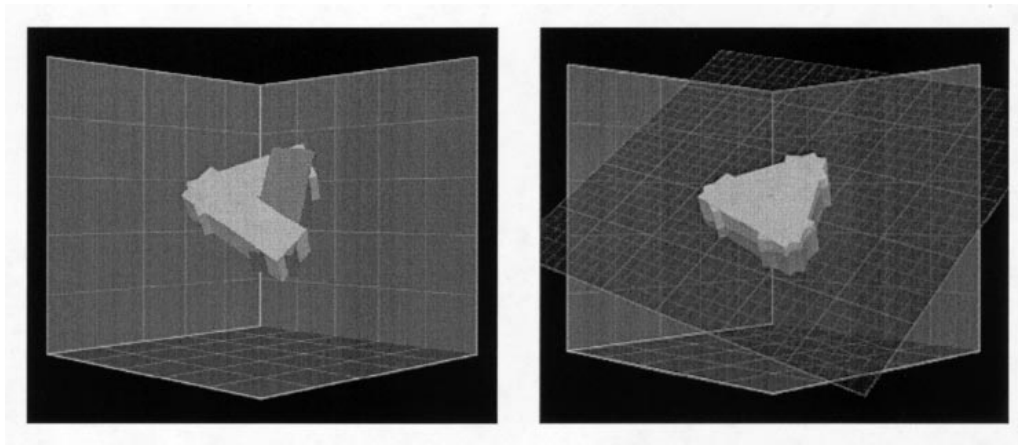


Figure 2.3 – Screen shots from the bimanual alignment task used by Hinckley et al (1998).

After alignment, participants completed a memory test by putting down the controller in their dominant hand, closing their eyes, and moving the controller back to the alignment position initially required (realignment). Participants performed the memory test both bimanually and unimanually in different orders with half of the participants using a bimanual approach first and a unimanual approach second, the other half using unimanual first. The difference in distance and rotational angle of the planar controller in the dominant hand were recorded before and after the memory test to measure accuracy in returning the controller to the alignment condition with eyes closed. Hand use affected distance

accuracy (returning the hand to the same position when using two hands was more accurate), as well as order of hand use approach. While unimanual realignment was less accurate than bimanual realignment for both order groups, participants who performed the unimanual realignment after completing the bimanual task were more accurate than those who performed the unimanual realignment first. This finding suggests the influence of a cognitive component to bimanual hand use – it is possible that participants who performed the bimanual realignment first gained proprioceptive insight into realigning the controller that those who performed the unimanual realignment first did not.

Overall, findings from this research both support and go beyond the model of bimanual hand-use described in Guiard's Kinematic Chain theory. Observations from the first experiment describe participants using their dominant hand to manipulate the heavier, less manoeuvrable target object while holding the lighter, more manoeuvrable tool still in their non-dominant hand. Instead of manipulating the objects according to the biomechanical effort involved (moving the lighter object towards the heavier object requires less effort), participants maintained the less-active non-dominant frame-of-reference role described by Guiard with the lighter tool. Findings from the second experiment suggest a cognitive transfer of proprioceptive insight from bimanual to unimanual tasks, but not from unimanual to bimanual. Performing the bimanual alignment task first provided some advantage unaccounted for by biomechanical efficiencies alone, which is not predicted by Guiard's Kinematic Chain theory. This suggests that while the Kinematic Chain theory provides useful insight into effective bimanual hand use for HCI designers, there are cognitive aspects at play in bimanual interactions which are still relatively unexplored.

While Hinckley et al examined bimanual hand use with tangible objects in three dimensions, Leganchuk and colleagues investigated bimanual performance in a screen-based shape selection task with a puck and stylus (Leganchuk, Zhai, et al., 1998). The task involved precisely selecting a shape with a bounding-

box tool. They found that accurate shape selection is performed faster with bimanual input (both puck and stylus) than with unimanual input (stylus only) for their shape selection task, however their analysis of participant performance during the selection task indicated that the advantage of bimanual selection could not be accounted for by time-motion efficiency alone. They suggest two main factors that explain faster shape selection with bimanual input: First, an increase in time-motion efficiency is supported by simultaneous control of two selection points. Second, the ability to manipulate both control points simultaneously allows for visual offloading of proper placement of the bounding-box that is superior to the “guess-where-to-click-first” bounding-box approach afforded by unimanual use. Leganchuk et al found that the cognitive advantage provided by visual offloading in the bimanual condition scales up as the complexity of the selection task increases.

Not all HCI research examining potential cognitive differences between unimanual and bimanual interaction has found evidence supporting bimanual superiority. Owen and colleagues (Owen et al., 2005) carried out a comparison of unimanual (stylus) and two bimanual methods (puck and stylus) for the manipulation and matching of two curve control vertices. They predicted that by comparing unimanual curve control with “switching time” removed (time with the pen lifted off of the tablet in order to switch from controlling one control vertex to another) to bimanual curve control they could isolate any efficiency or accuracy advantage of the bimanual techniques attributable to cognitive enhancement rather than time-motion efficiency. Contrary to their hypothesis they found that with “switching time” removed from the unimanual performance data, adjusted task times were identical to completion times from the bimanual conditions. They did observe, however, that as the complexity of the curve manipulation increased (by removing on-screen markers for the control vertices) the bimanual efficiency advantages became more pronounced (i.e. task times increased for unimanual and bimanual approaches as difficulty increased, but bimanual task time increases were proportionally less than the unimanual task time increase). They suggest that a bimanual approach to curve-fitting without visible

control vertices allows for “conceptual integration” that a unimanual approach does not. The authors define “conceptual integration” as “when the user perceives and prefers to think of the operations of the two hands not as separate activities but as a single activity.” (Owen et al., 2005). This notion of conceptual integration is similar to Guiard’s description cooperative bimanual hand use, as well as Buxton’s description of “chunking” and “phrasing” in human computer interaction (Buxton, 1995). The authors also found that if a bimanual interface requires the splitting of visual attention between multiple targets it may actually lead to worse performance than a similar one-handed handed interface.

Shifting slightly from a focus on only bimanual interaction, Moscovich and Hughes (Moscovich & Hughes, 2008) investigated unimanual multi-finger interaction using a multitouch pad. They asked participants to complete a figure rotation and scaling task using a multi-finger unimanual approach and a multi-finger bimanual approach. The authors found that bimanual interaction was more error-prone than unimanual interaction when stimulus in their task was rotated 90 degrees to the finger span axis of participant’s hands. They predicted that certain combinations of position, angle and scale for task stimulus would support this result as the stimulus would visually match the movement affordances of a single hand more than discreet bimanual control point movement.

In summary, HCI research into bimanual interaction shows that although there is evidence for kinematic and cognitive advantage when using bimanual interfaces, uniform bimanual superiority cannot always be assumed. Several HCI researchers have noted that bimanual advantages vary by task (Balakrishnan & Hinckley, 2000), and that for some tasks bimanual interfaces are actually worse than comparable unimanual interfaces if the bimanual interface is poorly designed (Kabbash, W. Buxton, et al., 1994; Balakrishnan & Hinckley, 1999). Research has also shown that some bimanual interface designs require significant learning time in before they provide advantages over unimanual interfaces, especially when a

supposedly less-than-optimal sequential unimanual approach to the task has been widely adopted (Balakrishnan & Kurtenbach, 1999; Odell et al., 2004).

Although HCI research shows that the success of bimanual interface designs can vary greatly, several common attributes of successful bimanual interfaces have emerged. First, bimanual interface designs should be based on “real-world” analogs for the intended task as much as possible (Zelevnik et al., 1997; Hinckley et al., 1998; Moscovich & Hughes, 2008). Hinckley et al (Hinckley et al., 1998) specifically point out the relatively low cognitive cost of bimanual interaction that can be leveraged due to our experience with physical manipulation of real objects. Moscovich and Hughes (Moscovich & Hughes 2008) point out that a bimanual interface’s perceptual compatibility with real-world bimanual tasks which afford the simultaneous control of multiple parameters (especially the fine-grained control of two points) is a good indicator of the potential of that interface for increasing interaction performance compared to unimanual approaches. Second, bimanual interfaces should “chunk” or unify a task into salient motion-phrases in order to leverage our ability to combine multiple isomorphic sub-actions into complex gestures (Buxton, 1995; Latulipe et al., 2005; Owen et al., 2005). Third, bimanual interfaces should visually integrate system feedback for both hand positions within the same display space (Buxton, 1995, Owen et al., 2005). This concept of proper visual integration holds regardless of whether a user’s hands are coincident with the system display – as long as the system displays some integrated representation of hand position a user does not need to see their hands while interacting to experience bimanual interaction advantages (Balakrishnan & Hinckley, 1999).

2.3 Direct vs Indirect interaction

Besides affording bimanual interaction, multitouch displays also allow for a user’s hands to be co-located with a system’s display space. This affordance is contemporarily referred to as *direct* interaction, while traditional interaction with hands on an input device separate from the display is contrasted as

indirect. It is important to note that the terms *direct* and *indirect* have also been used in earlier HCI research to refer to command-line interfaces (indirect) and graphical representations of data and processes (direct) (Shneiderman, 1982, 1997). These terms have also been used to describe the motion mapping between input devices and system response (Jacob, 1996)– for example, forward motion on a controller resulting in proportionally similar upward direction of a screen cursor is more “direct” than the “indirectness” of forward motion on a controller being mapped to disproportionate changes in the rotational position of an on-screen dial. For the remainder of this thesis, I will use the terms to denote hands-off-display interfaces (indirect) and hands-on-display interfaces (direct). Early research into touch screen interfaces (the common form of direct interface studied in HCI research) identified the “fat finger” problem (Wigdor et al., 2009), which is the tendency for the large size of the human fingertip to occlude targets on the touch display leading into a reduction in selection accuracy, especially in designs where smaller targets were originally implemented for the smaller mouse cursor. However, it has been established that user performance with touch screen interfaces is comparable to mouse performance for targets as small as 1.7 x 2.2 mm (Sears & Shneiderman, 1991), depending on the resolution of touch sensing used in the display, stabilization software used to smooth touch detection, and display size.

Recent research has also shown that tactile feedback can improve the accuracy of direct interaction (Forlines & Balakrishnan, 2008). Forlines and Balakrishnan performed an experiment where they asked participants to select or cross targets via an indirect mouse interface, a pen-based direct interface, and a haptically-enhanced pen interface. They found that the indirect input outperformed direct input for “difficult” (smaller, larger distance to cross) targets in terms of efficiency and accuracy, but that tactile feedback improved selection time in cases using the direct interface where occlusion of the target by the users body prevented them from seeing that the selection was complete.

Research has also shown that direct touch and multi-finger interaction on large multitouch displays can improve selection time of finger-sized targets compared to indirect mouse interaction (Kin et al., 2009). Kin, Agrawala and DeRose found that direct touch interaction in a multiple target selection task was 83% faster than indirect mouse-based interaction. They also found an efficiency advantage for bimanual two-finger target selection over unimanual direct target selection which led to an average selection time twice as fast as indirect mouse-based selection. (Note: they found no statistical difference in selection time between bimanual multi-finger target selection and two-finger selection). Multi-finger target selection introduced a significant increase in errors compared to one-finger direct-touch target selection, but number of targets had a greater effect on accuracy than interface style.

In research investigating the affordances of touch interaction for senior-aged users, McLaughlin, Rogers and Fisk found that direct touch screen interaction increased task efficiency when it used in interface designs with a strong match between the physical input affordance of the interface and the requirements of the task (McLaughlin, Rogers, & Fisk, 2009). Participants in their research were required to perform four different task types (precision, repetitive, ballistic, and pointing) while also interacting with a game interface while varying their division of attention between the game interface and the separate interface task. The precision and repetitive task types were ideally matched to an indirect rotary encoder for input, and the ballistic and pointing tasks were ideally matched for using a direct touch screen for input. For the precision task participants were required to select a precise value on a slider through small increments or a precise value through repeated incrementing/decrementing a numerical value in a number selection field. For the repetitive task participants were required to select a value on the extreme end of a slider in the ballistic task and to increment the numerical value of a number selection field by a few values by tapping an up or down arrow icon in the pointing task. The researchers found that when task and interface style was properly matched (i.e. when pointing and ballistic interaction tasks were performed with the touch screen and precision and repetitive interaction

tasks were performed with the rotary encoder), increased age and decreased level of attention devoted to the interface task had less of a negative impact on task efficiency. In other words, matching the direct touch screen interface to the interface tasks best-afforded by touch screen interaction (pointing and ballistic slider manipulation in this case) improved task accuracy, especially for older participants and in situations where increasing attention was devoted to another task.

To summarize the direct/indirect interaction research recounted here, direct interaction via single-touch and multitouch screens have been shown to be accurate and efficient for a number of specific interaction tasks. The “directness” of multitouch interaction has been found to support certain tasks better than indirect interaction in terms of both biomechanical time-motion efficiency and cognitive support. In other words, lifting a finger from the screen and placing it on a target some distance away from the previous target can be quicker and more accurate for certain tasks not only because the interaction physically affords jumping between two disparate points on the screen quickly, but also because the interaction is a better fit for the mental representation of the task.

2.4 The Cognition of Creativity

My personal background as a student of New Media art practice and as a teacher of design students has often prompted me to consider human creativity from both cognitive and behavioural perspectives. Although human creative capability is often framed as mysterious, innate, and primarily personality-driven (especially by students looking for mercy marking and creativity consultants looking for clients), research from psychology and the social sciences has a long and successful history of studying and demystifying creative behaviour. For example, one of the most important aspects of human creativity that is not often discussed is the socially-constructed nature of creativity (Amabile, 1996). The human ability to recognize creative behaviour in oneself or others relies on a fine balance of novelty and familiarity by the creativity evaluator. In order to be recognized as “creative”, an individual, artefact, idea, or pattern

must be unique enough to those evaluating the creative thing that they recognise its novelty, but also familiar enough to be contextualized as “understandable” or “useful” to the evaluators. Individuals who exhibit novel behaviours, ideas, or artefacts that are not able to be contextualized by some peer-group are often ostracized and considered to be insane or bizarre in some way. In fact, one of the hallmarks of mental illnesses such as schizophrenia is “magical thinking”, or novel ideation that seems to have little connection to commonly accepted reality. Psychological research has established strong links between creativity and mental health challenges such as schizophrenia (Hasenpus & Magaro, 1976; Keefe & Magaro, 1980; Glazer, 2009; Nichols, 2009, to name just a few).

Creativity research has taken the form of psychometric models of creative ability (Guilford, 1967), classifications of creative contributions (Sternberg, Kaufman, & Pretz, 2002), classifications of creative individuals (Kaufman & Beghetto, 2009), and investigations of the relationship between mental imagery and creative performance (Finke, 1990; Verstijnen, van Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998) to outline but a handful of research threads. An exhaustive overview of modern creativity research is beyond the scope of my thesis, but this brief outline of the variety and richness of creativity research is intended to give some indication of the depth and diversity available to creativity researchers.

2.5 Human Creativity and Divergent Thinking

A significant body of work in psychological research has been devoted to developing a clearer understanding of the influences and outcomes of physiological activity on human creativity. While it is acknowledged that human creativity is expressed in a great variety of behaviours and contexts, specific creativity theories and measurable constructs have clarified the relationships between specific measurable physical conditions (such as brain activity) and creative output (see Fink et al., 2007 for an overview).

A common approach to understanding problem-solving processes from creativity research is to focus on one of two mental strategies: convergent or divergent thinking (Guilford 1967). Measuring convergent thinking usually entails examining logical ability, mental speed, and operational accuracy. Divergent thinking skills are often associated with creativity, and consist of mental operations that produce multiple novel solutions to a problem. While many approaches to evaluating divergent thinking exist, one of the most common used in psychological research is the Alternate Uses Task (or AUT - Christensen et al., 1960), which measures a participant's ability to generate alternate uses for everyday objects. (The Alternate Uses Task will be discussed in more detail later in the chapter.) Existing research shows that scores from Alternate Uses Task research strongly correlate to creativity in the "real world" (Torrance, 1981, 1998; Heilman et al., 2003). The Alternate Uses Task has also been used to explore the underlying mental and neurological processes that influence divergent thinking (Gilhooly, Fioratou, Anthony, & Wynn, 2007). Understanding and supporting divergent thinking has important implications in a wide range of areas, including childhood social development (Wyver & Spence, 1999), workplace group dynamics (Dyne & Saavedra, 1996), product design (Dahl & Moreau, 2002), engineering (Dym, Agogino, Eris, Frey, & Leifer, 2005) and entrepreneurship (Ames & Runco, 2005).

2.5.1 Divergent Thinking and Inter-Hemispheric Interaction

Long-standing research has linked increased creative performance with increased Inter-Hemispheric Interaction (Lewis 1979, Hoppe 1988). Inter-hemispheric interaction (IHI) is the interaction of the right and left brain hemispheres through the connecting brain tissue of the corpus callosum. Certain behaviours and mental operations require information to be shared between both brain hemispheres, which increases inter-hemispheric activity. Recent research has shown that exercises that increase IHI correspondingly increase divergent thinking ability for certain individuals (Shobe et al., 2009). Shobe and colleagues describe the increased divergent-thinking performance of strong-handed participants who completed the Alternate Uses Task after performing Bilateral Eye Movements (or BEM - an exercise

which stimulates IHI by moving the eyes back and forth horizontally deliberately in full sync) for 30 seconds. This effect is temporary. Researchers observed a decline of divergent thinking performance to pre-BEM levels after 7-9 minutes of participation in the AUT. The manipulation of IHI via symmetric bilateral body movements such as BEM suggests a potential link between the types of body motion involved in bimanual interaction via large multitouch displays and divergent thinking ability – that is, if moving the body in bilaterally-synced ways increases IHI, and increased IHI boosts divergent thinking ability, it is possible that the bilateral movement of both hands during bimanual interaction may increase IHI and thus boost divergent thinking ability for users of multitouch displays. This relationship between symmetric bilateral body movement and creative performance identified by Shobe, Ross, and Fleck and its potential application to computer interaction via large multitouch displays is the crux of the line of inquiry for my thesis research.

2.5.2 Other Physiological Influences on Inter-Hemispheric Interaction

There are several other human characteristics besides bilateral body movements (such as eye movement) that affect Inter-Hemispheric Interaction. For example, handedness is one of the primary predictors of IHI strength - strong-handed people (those who are predominantly right or left handed) typically exhibit lower IHI than mixed-handed people (Propper, Christman, & Phaneuf, 2005). This relationship is borne out by the results of Shobe et al – mixed-handed participants saw little-to-no change in their Alternate Use Task scores in the BEM condition – but they provided scores consistently higher than any strong-handed group in the non-BEM condition. Research has also found that inter-hemispheric activity is inhibited during unimanual movements (Vercauteren, Pleyzier, Van Belle, Swinnen, & Wenderoth, 2008). Vercauteren et al hypothesize that inhibiting IHI during unimanual muscle activation prevents mirror activity in the motor cortex of the hemisphere controlling the non-moving hand. As the primary biomechanical difference between traditional unimanual mouse-driven

and bimanual multitouch interaction is the number of hands used during interaction, it is possible that bimanual interaction afforded by large multitouch displays will influence IHI measurably.

Another major human characteristic that differentiates IHI among individuals is gender. IHI in males is observably different from females. Whereas successful divergent thinking in creative males is characterized by “massive” changes in IHI amplitude and coherence, IHI in similar divergent thinking in females is more localized to specific regions inter-hemispheric tissue (Razumnikova, 2004). This neurological difference did not result in any observable gender-based Alternate Uses differences in (Shobe et al., 2009), but HCI researchers Hinckley, Pausch, Proffitt, Patten, and Kassell (Hinckley et al., 1997) observed that males were more sensitive to reversing hand roles in their bimanual tool-to-object task, which may relate to physiological differences in corpus callosum structure between males and females (DeLacoste-Utamsing & Holloway, 1982, Westerhausen et al., 2004).

2.6 The Alternate Uses Task

The Alternate Uses Task, originally introduced by Christensen et al (1960) and widely used in the psychometric research of Guilford (1967), involves participants generating new uses for 15 everyday objects. During the task, participants are provided with the name of an object and an example of the object’s typical use and then given one minute to list as many new uses as they can for the object. These new uses can then be analyzed and used to compare divergent thinking performance between individuals or groups.

One of the strengths of the Alternate Uses Task as a divergent thinking measurement tool is that several well-known psychological and neurological phenomena are at work as participants complete the task. This means that by measuring performance of the Alternate Uses task, we can infer the status of cognitive phenomena such as inter-hemispheric interaction. For example, the Alternate Uses task relies on participants’ capacity to overcome functional fixedness. Functional fixedness is the rigid mapping of

known objects to specific uses, excluding the potential uses of these objects for other purposes (Adamson, 1952). This typically occurs as our understanding of the world solidifies during the transition out of early childhood, but can be overcome later in life through various means. Recent research (Gilhooly et al., 2007) has identified four main mental strategies that humans use to overcome functional fixedness while completing the Alternate Uses task: autobiographical memory access, property inspection, broad use analysis, and mental disassembly. Memory access, during which objects are matched to past experiences to identify novel uses of the object in the participant's past experience, relies on episodic memory and is thought to be cognitively inexpensive; it is most likely the first approach participants will take to solving the Alternate Uses task. The last three methods all rely to some degree on semantic memory and analogical mappings, which require more cognitive resources which are linked to brain areas across both hemispheres to utilize.

Analysing participant performance on the Alternate Uses task is typically done via quantitative assessment of AUT scores generated via one of several scoring approaches. Some scoring approaches include asking participants to pick their top two responses (Silvia et al., 2008) and using third-party judges to rate the originality of participant responses (Amabile, 1982, 1996). Contemporary research (Chamorro-Premuzic & Reichenbacher, 2008), including the research of Shobe et al (2009) which is the primary inspiration for my thesis research, involves scoring participant responses on the Alternate Uses task along five subscales or dimensions: appropriateness, detail, fluency, originality, and categorical distinctiveness.

2.6.1 The Alternate Uses Subscales

The specific details of scoring AUT responses along these subscales are discussed in more detail later in Chapter Four but are briefly outlined here as an overview:

- *Fluency* is the total number of uses per item the participant responds to regardless of appropriateness or “usefulness”.
- *Appropriateness* is scored by assigning a single point to responses that are useful and/or appropriate – this is to screen for responses that are not considered valid alternate uses.
- *Detail* is the amount of elaboration provided in the response.
- *Flexibility* or *categorical distinctiveness* is the number of categorically distinct responses per item.
- *Originality* is the number of unique responses compared to all responses given by all participants. Points are given according to the frequency of a response compared to the responses of all participants

These sub-scores can be added into a single score per item/trial or analysed separately along each subscale. A single trial consists of one item from the list of Alternate Uses objects and the corresponding alternate uses given by the participant, and each trial is scored individually. Shobe et al found that bilateral body movement (specifically bilateral eye movement) had a measureable effect on the *flexibility* and *originality* performance of strong-handed participants. Hence, these two subscales are of primary interest in my thesis research.

2.7 Human Computer Interaction and Creativity

While the bulk of my discussion of creativity research has focused on psychological and neuro-cognitive evaluations of divergent thinking, creativity has also been the subject of some notable research with the field of human-computer interaction. HCI research into creativity has included descriptions and recommendations of systems features that *should* support user-creativity based on descriptions of the creative process. For example, Shneiderman has described the four phases of creative endeavours that could be best supported by software as information collection, relation, creation, and donation

(Shneiderman, 2000). Based on the widely disseminated *flow* research of Mihaly Csikszentmihalyi, Carroll and colleagues have described a framework called the Creativity Support Index which may be used for evaluating the creativity support level of interfaces by having users score an interface in terms of Results and Effort, Expressiveness, Exploration, Immersion, Enjoyment and Collaboration (E. A. Carroll, Latulipe, Fung, & Terry, 2009). Within HCI the creativity construct of divergent thinking has been used to examine information sharing within groupware contexts (Warr & O'Neill, 2006; Hailpern, Hinterbichler, Leppert, Cook, & Bailey, 2007; Farooq, Carroll, & Ganoe, 2005) and in evaluating how information discovery may be supported by using image and text compositions as surrogates in representing information collections (Kerne et al., 2007). All of these descriptions and evaluations have focused on particular design patterns used in UI design and their affordances for information organization and sharing; none have explored the effects of body movement or physical interface style on divergent thinking or other aspects of creativity.

2.8 Research Questions

While a rich body of human computer interaction research into bimanual interaction, multitouch display interfaces, and creativity support exists, there have been no investigations into the effect of bimanual multitouch interaction on divergent thinking to date. Also, findings from bimanual and direct/indirect interface research do not offer any specific predictions on how divergent thinking performance as measured by the Alternate Uses Task may be affected by bimanual or direct interaction. My thesis then established a line of exploratory inquiry into this area, primarily guided by the findings of Shobe et al from cognitive psychology. With this research in mind, my thesis is intended to explore these specific questions:

- Does unimanual multitouch interaction affect both strong and mixed-handed participants' *flexibility* and *originality* scores on the Alternate Uses Task differently than unimanual mouse-based interaction?
- Does bimanual multitouch interaction increase strong-handed participants' *flexibility* and *originality* scores on the Alternate Uses Task compared to unimanual multitouch and unimanual mouse-based interaction?
- Does bimanual multitouch interaction increase strong-handed participants' *flexibility* and *originality* scores on the Alternate Uses Task to the level of mixed-handed participants' *flexibility* and *originality* scores?
- Does unimanual multitouch and unimanual mouse interaction increase strong-handed participants' scores on all of the Alternate Uses Task subscales to the level of mixed-handed participants' AUT scores?
- Does unimanual multitouch interaction affect both strong and mixed-handed participants' *fluency*, *appropriateness* and *detail* scores on the Alternate Uses Task differently than unimanual mouse-based interaction?

I acknowledge that with no previous HCI work to directly base my specific research questions on, I am in somewhat exploratory territory. However, with a strong base of psychological and cognitive research to guide me, I have undertaken an empirical inquiry into these questions by adjusting the experimental work of Shobe et al to fit an ecologically valid HCI-centered experimental framework. The next chapter in this record (Chapter Three) outlines this framework in more detail, including the identification of specific experimental hypotheses and variables, a description of research instruments, and a discussion of experimental measures.

CHAPTER 3: EXPERIMENTAL DESIGN – FRAMEWORK

3.1 Overview

As discussed in Chapters One and Two, the majority of HCI research into bimanual interaction has focused on parallelism, time-motion efficiency and cognitive advantages based on task representation analogous to “real-world” hand use. Recent findings from cognitive psychology suggest that bilateral body movements also increase divergent thinking ability in strong-handed individuals (Shobe et al., 2009). This chapter outlines a research framework for exploring whether these findings extend to bimanual interaction with multitouch interfaces, extending HCI research on bimanual interfaces beyond biomechanical and task-specific analog-imitation frameworks.

My research framework is primarily based on the research of Shobe et al (Shobe et al., 2009) in their bilateral eye movement study (BEM). Their goal was to test whether bilateral eye movement affects inter-hemispheric interaction (IHI) in a way that alters divergent thinking, as measured by the Alternate Uses task (AUT). They found that strong-handed participants (i.e. people who are left or right handed, not ambidextrous) in the experimental BEM group had *originality* and *flexibility* scores that were on average higher than strong-handed participants in the non-BEM group. Strong-handed BEM participants had a mean *originality* score of 3.09 (SE = 0.46) and a mean *flexibility* score of 2.22 (SE = 0.2) versus the strong-handed non-BEM mean *originality* score of 1.4 (SE = 0.53, $F(1,30) = 5.78$, $p = 0.02$, $\eta^2_p = 0.12$) and *flexibility* score of 1.56 (SE = 0.23, $F(1,30) = 4.71$, $p = 0.04$, $\eta^2_p = 0.14$). They theorized that the BEM exercise increased IHI for strong-handed participants which contributed to an increase in *originality* and *flexibility* scores. My research has a similar goal to Shobe et al’s research: to test whether two-handed interaction (as afforded by desktop-monitor-sized multitouch screens) affects divergent thinking (as measured by the AUT) in a similar way.

3.2 Hypotheses

To test the relationship between bimanual interaction and divergent thinking, I compared AUT scores from participants using three different interfaces in a between-participants study: A bimanual multitouch interface, a unimanual multitouch interface, and a traditional unimanual mouse interface. The two distinct unimanual interfaces are included in order to explore the potential effects of direct vs indirect interaction on divergent thinking and provide baseline non-bimanual interaction condition to compare against. While theory from HCI and cognitive psychology does not specifically predict divergent thinking differences between these two interaction styles, the large body of HCI research that emphasizes the effect that different interface styles have on mental representation of the task and perceptual compatibility with real-world tasks hints at possible differences between hands-on-screen unimanual interaction and hands-on-mouse interaction, as discussed in section 2.3.

3.2.1 Hypothesis One

The main difference between unimanual multitouch and mouse interaction is the degree of “directness” in interacting with the interface. HCI research has shown differences in selection accuracy and implied differences in mental task representation and perceptual similarity to “real-world” physical interaction between direct (multitouch display) and indirect (mouse) interaction. None of these differences are directly tested by the Alternate Uses Task, therefore *originality* and *flexibility* scores for the unimanual interfaces (unimanual multitouch and mouse) should be similar. Testing this hypothesis first allows for the possibility of collapsing unimanual and mouse scores into a single set of strong-handed interface scores if evidence is found to support the hypothesis. Based on Shobe et al’s findings, I hypothesize the following:

H1: *Flexibility* and *originality* scores from both strong and mixed-handed participants using the unimanual multitouch interface will be the same as scores from strong and mixed-handed participants using the mouse interface.

3.2.2 Hypothesis Two

Shobe et al found that of the five AUT subscales, *originality* and *flexibility* were boosted by bilateral eye movement for strong-handed participants. If bimanual interaction via large multitouch displays has a similar influence on divergent thinking as bilateral eye-movement does, we should see a similar increase in these subscores for strong-handed participants using the bimanual interface in my research as well. If there is evidence to support H1, *flexibility* and *originality* scores for mouse and unimanual interface styles will be combined to provide a larger data set for testing H2, otherwise strong-handed bimanual *flexibility* and *originality* scores will be compared against unimanual multitouch and mouse scores as three separate groups.

H2: *Flexibility* and *originality* scores from strong-handed participants using the bimanual multitouch interface will be higher than scores from strong-handed participants using the unimanual multitouch and mouse interfaces.

3.2.3 Hypothesis Three

The boost in *flexibility* and *originality* scores for strong-handed participants in Shobe et al's research did not exceed mixed-handed scores for these subscales. Shobe et al concluded that the bilateral eye movement exercise increased inter-hemispheric interaction for strong-handed participants to levels equivalent to trait IHI in mixed-handed participants. Unless the effect of bimanual interaction on strong-handed participant's divergent thinking ability is amplified above that of mixed-handed participants using the bimanual interface through some unknown mechanism, strong-handed and mixed-handed performance on the AUT should be the same.

H3: *Flexibility* and *originality* scores from strong-handed participants using the bimanual multitouch interface will be the same as scores from mixed-handed participants using the bimanual multitouch interface.

3.2.4 Hypothesis Four

Shobe et al found that mixed-handed participants exhibited consistently higher Alternate Uses Task scores for *fluency*, *appropriateness*, *detail*, *flexibility* and *originality* independent of exposure to the bilateral eye movement condition. It is theorized that mixed-handed individuals have higher trait inter-hemispheric cooperation than strong-handed persons, which is reflected in greater divergent thinking ability and higher AUT scores. As it is predicted that inter-hemispheric interaction will only vary among strong-handed participants and only between bimanual and the two unimanual interfaces, AUT scores for mixed-handed participants assigned to any of the three interface styles should be similar.

H4: Scores across all AUT subscales will be higher for mixed-handed participants using unimanual multitouch and mouse interfaces than strong-handed participants using unimanual multitouch and mouse interfaces.

3.2.5 Hypothesis Five

Answering my first hypothesis (H1) already tests for potential differences between direct and indirect interaction on *originality* and *flexibility* scores. As previously stated, HCI research on bimanual and direct/indirect interaction hints at possible differences between hands-on-screen unimanual interaction and hands-on-mouse interaction, but does not explicitly predict differences that would be measurable as AUT subscore differences. Testing this hypothesis and finding evidence to reject it may suggest new directions for future direct/indirect interaction and multitouch research.

H5: *Fluency, appropriateness, and detail* scores from both strong and mixed-handed participants using the unimanual multitouch interface will be the same as scores from both strong and mixed-handed participants using the mouse interface.

3.3 Demographic Variables

I collected demographic data from participants after they completed my main experimental task (interacting with a computerized version of the Alternate Uses Task, described later in the chapter). This data was collected post-task rather than pre-task (as is usually done in HCI and psychological research) on order to minimize interface variability for participants assigned to the bimanual and unimanual multitouch interfaces – the demographic survey was implemented as a web survey which was best served by a mouse interface. (A copy of the survey questions is included in Appendix B.) The demographic data collected includes gender, age group, native language, English fluency (self-report), and experience with both mouse and multitouch interface. I also had participants complete exercises post-task to identify handedness via the Edinburgh Handedness Inventory (EHI) and verbal English fluency via the FAS test, both of which are described in section 3.6 of this chapter. Shobe et al's research identified handedness as a major factor in the effect of bilateral eye movement on divergent thinking, and spoken English fluency is vital to maintaining the effectiveness of verbal versions of the Alternate Uses Task as a divergent thinking measurement tool. The reason for using a spoken version of the AUT in my research is covered later in section 3.5. These demographic data (especially handedness and verbal fluency) were used to test my hypotheses and explore other factors that may influence divergent thinking performance in my study.

3.4 Independent Variables

From an experimental design perspective, the individual demographic such as age, handedness, and spoken English fluency are independent variables (IV's) that will not be manipulated during experimental sessions, and must be controlled for as much as possible through measurement before or

after the experimental task. Besides demographic variables, the other independent variables in my study are interface style (mouse, unimanual multitouch, and bimanual multitouch) and Alternate Uses Task objects.

3.5 The Computerized Alternate Uses Task

To facilitate the investigation of the effects of bimanual interaction on divergent thinking using the Alternate Uses Task, I created a computerized version of the AUT. The computerized AUT displays the name of an object from the AUT object list, as well as a 3d model of that object, which can be rotated and resized via multitouch or mouse hardware. Each interface style maps the rotate and resize functions uniquely to match the affordances of each interaction technique, as outlined in Figure 3.1. It is worth noting that the bimanual interaction supported by the software design is considered a parallel symmetric bimanual interface by HCI standards – both hands share an equal and time-parallel role in altering the scale and rotation of the virtual objects. An example screen shot from two of the interface conditions (mouse and bimanual multitouch) is provided as Figures 3.2 and 3.3, and a screenshots of the 3d AUT object models is provided as Figure 3.4.

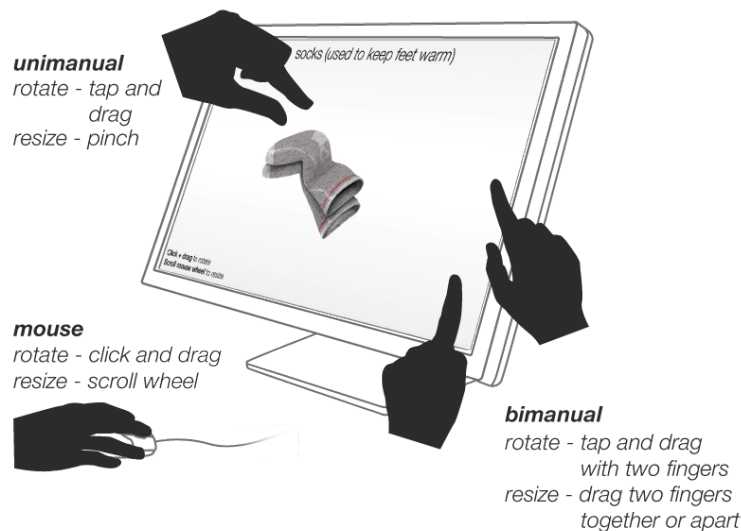


Figure 3.1 - Mappings of rotate and resize functions to interface styles for the computerized AUT.

brick (*used as building material*)



Click + drag to *rotate*
Scroll mouse wheel to *resize*

Figure 3.2 - Screenshot of computerized AUT displaying an object for the mouse interface.

socks (*used to keep feet warm*)



Touch + drag with two fingers to *rotate*
Drag fingers together or apart to *resize*

Figure 3.3 Screenshot of computerized AUT displaying an object for the bimanual interface.



Figure 3.4 - 3d models of AUT objects created for the computerized AUT.

The Alternate Uses Task software differs from the traditional administration of the AUT in three significant ways: first, participants are shown a 3d representation of the object along with the name and normal use of the object. Second, participants are encouraged to manipulate the 3d representation of the object while they generate new uses for it. Third, participants are asked to speak aloud their new uses as they generate them, rather than writing them down (the traditional AUT method for recording responses). Because my study examines divergent thinking while using interfaces which occupy the

hands, the traditional written form of the AUT was inappropriate. Several previous creativity studies have outlined verbal versions of divergent thinking tests including the AUT (Reese, Lee, Cohen, & Puckett, 2001; Gilhooly et al., 2007). Furthermore, Gilhooly et al found no difference in AUT performance due to verbal overshadowing – think-aloud responses were not found to be measurably different than written responses.

It is worth noting that just like the traditional paper-administered AUT, my computerized AUT is designed to be a divergent thinking measurement tool, not a divergent thinking enhancement tool. These interface styles correspond to interfaces commonly used in real-world computer use (particularly mouse-based interfaces) which is intended to supporting the ecological validity of the findings from this research. The interface styles supported by the computerized AUT also allow us to identify how the direct on-screen interaction that touch interfaces afford influences divergent thinking separately from the effects of bimanual hand movement (i.e. comparing unimanual multitouch vs. bimanual multitouch).

The computerized AUT software handles audio recording through an external microphone, which records participant’s verbal responses while they interact with the software. The software was designed for use with a 3M M2256PW 22” capacitive multitouch (Figure 3.5) screen using the PyMT framework (Hansen et al 2009). Because the PyMT framework can handle many different multitouch hardware configurations, the computerized AUT can be easily reconfigured for different display sizes or multitouch sensing technologies if needed for future research. The 3d models of AUT objects were modeled in 3D Studio Max.

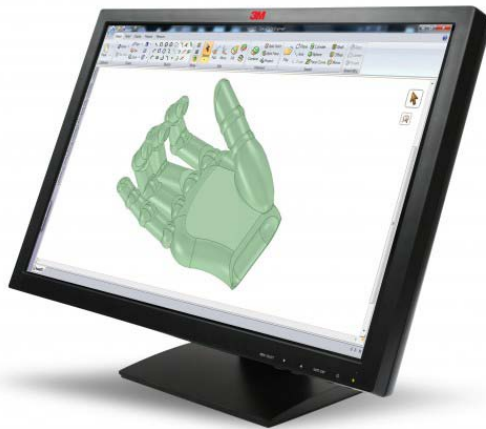


Figure 3.5 - Promotional photo of the 3M M2256PW 22" capacitive multitouch display

3.5.1 The Procedure

Participants in my study were randomly assigned to a single interface style (mouse, unimanual, or bimanual) for a between-participants design. The rationale for this type of experimental design is fully explained in the next chapter (Chapter Four – Experimental Methodology); briefly stated, however, divergent thinking measurements like the Alternate Uses Task assume uniform novelty in exposing participants to task objects – objects are not repeatable by an individual participant, nor are any two different objects considered equivalent in divergent thinking potential. Participants completed the computerized Alternate Uses Task via their assigned interface style then completed the post-task verbal fluency test and used a mouse to fill out the web-based demographic and handedness surveys. A more detailed discussion of task completion and post-task surveys is included in Chapter Four.

3.5.2 Dependant Variables

As discussed in Chapter Two, various scoring schemes for the Alternate Uses Task have been used in creativity research examining divergent thinking. Shobe et al used a scheme which evaluated each set of participant responses along five subscales: *fluency*, *appropriateness*, *detail*, *flexibility*, and *originality*.

The theoretical rationale for each of these subscales has been discussed in section 2.6.1, and a detailed description of transforming participant responses into subscale scores is included in Chapter 4.

3.6 Demographic Measures – English fluency and Handedness

To measure English verbal fluency participants were asked to complete the FAS test. In the FAS test participants are given one minute per letter to say aloud as many words as they can think of that begin with the letters F, A, and S. Participants are also asked not to use proper nouns or words with the same root, i.e. friend, friendly, friendlier. The number of valid words for each letter are tallied and combined (total number of valid F words + total number of valid A words + total number of valid S words) to give a verbal fluency score for each participant. These scores can be compared against normalized score sets for various populations. To compare participant FAS scores from my study I used score data from data from a sample of 1300 cognitively-intact Canadians between the ages 16 to 95 (Tombaugh et al 1999).

The Edinburgh Handedness Inventory (Oldfield, 1971) asks participants to choose their preferred hand for a number of common manual activities such as writing, using a spoon, and opening a lid (A copy of the inventory is included in Appendix B.) Possible hand-use preferences are:

Left Always Left Usually No Preference Right Usually Right Always

Responses are tallied according to the following rubric:

- Two points to a cumulative “Left Score” for every response of “Left Always” and two points to “Right Score” for every “Right Always” response.
- One point to “Left Score” for every response of “Left Usually” and one point to “Right Score” for every “Right Usually” response.
- One point to both “Left Score” and “Right Score” for every response of “No Preference”.

A final handedness score is calculated by adding “Left Score” to “Right Score” to get a cumulative total score (CT), subtracting “Left Score” from “Right Score” to get a difference score (D), and dividing the difference by the cumulative total ($D/CT * 100$). Handedness scores range from -100 (completely left-handed) to +100 (completely right-handed). Chamorro-Prezumic et al and Shobe et al used these scores to group AUT participants into strong-handed participants (scores of +/- 77.5 or higher/lower) and mixed-handed participants (scores between -77.5 and + 77.5). I grouped the EHI scores from my participant responses similarly. While the original Edinburgh Handedness Inventory outlined a much more conservative standard for mixed-handedness (scores between +/- 40 were considered ambidextrous), based on Shobe et al, I split the handedness groups along +/- 77.5.

CHAPTER 4: EXPERIMENTAL DESIGN – METHODOLOGY

4.1 Overview

To test the hypotheses from Chapter 3 I designed an exploratory experimental investigation of the potential relationship between interface style and divergent thinking. This investigation takes the form of a between-groups comparison of AUT performance by participants using one of three interface styles: a bimanual (two-handed) multitouch interface, a unimanual multitouch interface, and a unimanual mouse-driven interface. This chapter reports my experimental methodology including participant demographics for my study, as well as experimental setting procedure. It also outlines preparation for the quantitative analysis of data from the study, including Alternate Uses Task, Edinburgh Handedness Inventory, and FAS verbal fluency scoring, as well as an outline of appropriate statistical approaches for analysing the data.

4.2 Participants

68 participants (three of whom were pilot-study participants) were recruited via an opportunity sample from the Simon Fraser University Surrey undergraduate and graduate population. During the participant recruitment process, special emphasis was placed on the need for participants to be fluent in spoken English. (As participants would be stating aloud their new uses, they should be comfortable expressing the new uses they generate in spoken English.) During the recruitment process potential participants were also informed that they would be given a \$10 Blenz (coffee shop) gift card in compensation for their participation. The study was advertised as the “Computers and Creativity” study in order to communicate some notion of the nature of the research without divulging details that could have biased the participant’s knowledge and expectations of the research session.

The 65 participants (33 female, 32 male) of the main study were randomly assigned to each interface style, with 22 participants being assigned to the mouse (11 female, 11 male) and bimanual (12 female, 10 male) multitouch interfaces and 21 participants assigned to unimanual multitouch (10 female, 11 male). 40 of the participants self-identified as native English speakers (25 as non-native), and all participants claimed verbal English fluency. The majority of participants' ages fell within the 18 to 21 year old range, with considerable groups of participants in the 22 to 25 and 30 to 50 age ranges as well (18 to 21 years old: 28 participants, 22 to 25 years old: 14 participants, 26 to 29 years old: 9 participants, 30 to 50 years old: 13 participants, and one 50+ participant).

The vast majority of participants self-reported as daily mouse users (50 daily, 8 often, 4 sometimes, 3 rarely), and smaller majority self-reported as daily multitouch users (30 daily, 6 often, 13 sometimes, 16 rarely). Five participants assigned to the unimanual interface and six assigned to the bimanual interface reported as rare multitouch users, however all participants elicited their willingness to continue in the multitouch conditions after manipulating a warm-up object (the warm-up period is described in more detail in section 4.6). All but one of the participants self-identified as daily computer users (one participant responded that they use a computer "often"). 48 of the participants were scored as strong-handed by the Edinburgh Handedness Inventory (EHI) (using the +/-77.5 strong/mix split; 43 right-handed, 5 left-handed) and 17 participants scored as mixed-handed (7 female, 10 male). Arranged by interface style group, three of the mouse participants scored as mixed-handed (19 strong), seven of the unimanual multitouch participants scored as mixed-handed (14 strong), and seven of the bimanual multitouch participants scored as mixed-handed (15 strong). Details of the EHI scoring and FAS verbal fluency results for the participants are discussed in more detail sections 4.9 and 4.10.

4.3 Setting

Both pilot and experimental sessions were held in a small room attached to the BioMedia/Tangibles lab (room 3930) at the SFU Surrey campus. The room was furnished with a comfortable chair for participants to sit in, a smaller chair for the facilitator, and a table with the session apparatus on it (the multitouch monitor, a laptop, and a mouse when appropriate). The monitor was angled back so as not to be perpendicular to the table surface (approx 20° from perpendicular), and this angle was kept consistent across all participation trials. A microphone on a mic stand was set up to the right of the table in order to record participant responses during the task. The room has floor-to-ceiling windows with heavy curtains, which were kept closed in order to keep ambient lighting and monitor brightness consistent between sessions. Pilot and experimental sessions took place during August and September of 2011.

4.4 Assumptions

My study design makes several assumptions in attempting to investigate the effects of bimanual interaction on divergent thinking while working within the time and resource constraints of a master's thesis. First, the computerized AUT created for this study is assumed to be equal to the paper-administered AUT in its ability to elicit divergent thinking responses. While previous research has shown that stating divergent uses for AUT objects verbally (as is done with the computerized AUT) is not significantly different than written responses in terms of the number and quality of responses participants provide (Gilhooly et al., 2007), it is possible that some other effect introduced by the computerized AUT (such as manipulating virtual objects on a computer screen vs. reading the name of an object from a piece of paper) may influence divergent thinking outcomes beyond predicted changes in IHI prompted by different interface styles. Ideally, a study testing this assumption would be run

(which would require many participants and a great deal of time for analysis) and computer AUT vs. paper AUT equality would be accounted for before using the computerized AUT for this study.

Second, my design assumes that the three interface styles (mouse, unimanual multitouch, and bimanual multitouch) differ in their influence on divergent thinking primarily in terms of inter-hemispheric-interaction (IHI), not other (potentially confounding) neurological phenomena. Shobe et al's study used brief but focused bilateral eye movement to stimulate inter-hemispheric-interaction *before* having participants fill out the paper AUT (in the BEM group), which may avoid neurological changes that could be introduced by attempting to affect IHI through gross and fine hand coordination while simultaneously engaging in verbal divergent thinking tasks.

Thirdly, my design assumes that using both hands in the bimanual interface condition will boost IHI (and consequently divergent thinking) enough to be measureable when compared to divergent thinking performance from the other interface style groups. Divergent thinking performance as measured by the paper-administered AUT varies greatly between individuals, and is heavily influenced by educational background, age, and life experience (Reese et al., 2001). An increase in divergent thinking ability attributable to bimanual human-computer interaction must be large enough and consistent enough to be detectable within a great deal of individual variation in divergent thinking performance.

It is also worth noting that since divergent thinking performance varies greatly among individuals, a within-participants design that compares divergent thinking performance of participants using different interfaces in sequence would more sensitive to changes in divergent thinking attributable interface style. This sort of within-participants design specifically not chosen for two reasons: first, my intent was to replicate Shobe et al's findings in the context of human-computer interaction, and their design was between-participants (BEM and non-BEM); second, a within-participants design using the AUT requires a set of unique task objects that are equivalent in divergent-thinking potential – participants could not be

given the same object twice while using different interface styles. As individual responses to an AUT object rely on personal memories of previous uses for the object as well as mental disassembly and analogical thinking (Gilhooly et al., 2007), compiling a list of task objects with similar divergent thinking potential for a group of participants would be extremely difficult, if possible at all.

4.5 Pilot Study

Three pilot sessions were run in order to check for apparatus robustness, practice the experimental session protocol, and identify potential unexpected creativity or response confounds brought about through the apparatus or the session protocol. Each session tested a different interface style through the entire set of AUT objects and was followed by an informal interview asking for feedback on the experimental protocol and usability aspects of the computerized AUT. Comments from the pilot participants resulted in minor instructional wording changes and refinement of several 3d models used in the computerized AUT. The pilot sessions also confirmed that a 30 minute session length was adequate. Before running the pilot sessions, I was particularly concerned that participants would need to be regularly prompted to manipulate the virtual objects of the computerized AUT while saying aloud new uses for the objects, however the all three pilot participants “played” with the objects while verbalizing divergent uses with minimal prompting.

4.6 Experimental Procedure

After being welcomed and asked to fill out an informed consent form, participants were given a brief overview of the experimental session and their task. In order to become more comfortable with the computerized AUT and their assigned interface style, participants were shown a familiarization object (a Utah teapot) in the AUT software and encouraged to take a few minutes to play with it while saying aloud new uses for it. (These uses were not recorded for analysis.) While introducing this warm-up object, the facilitator cued the participants on “proper” use of the interface by briefly interacting with

the object and explaining how the interface worked. This was of special importance for bimanual interface participants who may have been otherwise tempted to use two fingers on a single hand interact with the system. Participants were asked to inform the facilitator when they were ready to move to the next part of the session while interacting with the warm-up object. Participants appeared to adapt easily to their assigned interfaces, except for one participant who experienced minor difficulty due to long fingernails. After finishing with the familiarization object, participants were introduced to the Alternate Uses task portion of the session and encouraged to continually rotate and resize (“play with”) the Alternate Use objects as they say aloud new uses. The computerized AUT then displayed a virtual model from a list of 15 common objects for one minute, during which time participants manipulated the object via their assigned interface style and stated aloud their new uses for the object. Between each object, a screen of x’s was displayed and participants were asked if they were ready for the next object before proceeding. This continued until all fifteen objects had been shown. The order of AUT object presentation followed the order of the Form A version of the written AUT (Christensen et al., 1960) used by Shobe et al. The objects are listed in order in Appendix A.

Following completion of the Alternate Uses Task, participants completed a spoken version of the *FAS* fluency test (Strauss, Sherman, & Spreen, 2006; Tombaugh, Kozak, & Rees, 1999). Next, they then completed an online survey consisting of simple language fluency questions, a modified online version of the Edinburgh Handedness Inventory (Oldfield, 1971), and some basic demographic questions (age range, gender, and typical computer use – a copy of these questions can be found in Appendix B). The online survey was administered post-AUT (rather than beforehand, as is usually done) in order to minimize any potential interface style cueing effects caused by using a mouse, as the online survey must be completed with a mouse regardless of the experimental condition level assigned during the AUT. After completing the survey, participants were asked if they have any final questions about the experimental session and handed an envelope with their \$10 gift card.

4.7 Scoring the Alternate Uses Task

Before being submitted to statistical tests for analysis, participant responses from the Alternate Uses task had to be transformed from audio session recordings into brief utterances that can be scored. The 16 hours and 15 minutes (15 minutes per participant * 65 participants = 975 minutes) of Alternate Use response audio was transcribed into paragraphs of raw text via a paid transcription service. These paragraphs were then separated into discreet lists of alternate use statements, which were then transferred to a spreadsheet for scoring. Following the scoring scheme used by Shobe et al, the lists of alternate uses statements were scored along five subscales:

- *Fluency* – the total number of uses per object, regardless of appropriateness. 1 point per unique response per object
- *Appropriateness* – also known as *usefulness*. 1 point for each valid or “useful” response per object
- *Detail* – the amount of elaboration provided in the response, on a 0 to 5 point scale per response
- *Flexibility* or Categorical Distinctiveness – the number of object categories used in the set of responses for each object. 1 point for each category of use within a set of item responses
- *Originality* – the number of unique responses per object, compared to all responses given by all participants, binned into responses that are unique to 5%, 10% and 15% of the participants
 - 3 points for uses given by 0 to 5% of the participants
 - 2 points for used given by 6 to 10% of the participants
 - 1 point for used given by 11 to 15% of the participants

While these sub-scores can be combined linearly into a single score per object per participant which can then be used to calculate average scores per participant, Shobe et al (and the majority of the AUT researchers) tend to evaluate each subscale separately. However, since the subscales *originality* and

flexibility were sensitive to enhancement through inter-hemispheric-interaction triggered by bilateral eye movement, they are of particular interest.

4.8 Scoring with an external rater

A rater blind to the interface style assigned to each participant but familiar with the study was asked to complete *appropriateness*, *detail*, *fluency*, and *flexibility* scores for the lists of participant responses. The rater was also provided with detailed guidelines for scoring each of the subscales. While subscales such as *fluency* and *appropriateness* may seem straightforward and fairly simple to ascertain objectively, scoring *detail* and *flexibility* requires subjective assessments that must be applied consistently to create valid scores. Also consider that assessing creativity in any form (including divergent thought) is ultimately a subjective socially-constructed exercise (Amabile, 1982, 1996) – AUT scores do not provide an objective measure of divergent thinking since creativity is socially constructed. However, they provide a relative measure that can be compared between participants and independent variable groups. In order to compare creative performance on the AUT, scoring should be done with consistently applied judgement. To aide in this the following rubrics were provided to the rater:

- For *Fluency*: This a simple count of responses excluding any responses that are the same as the original use provided with the object, or if it is a repeat responses for that object per participant.
- For *Appropriateness*: This subscale is for filtering out responses that are unintelligible or “nonsense” responses. This is **not** a subjective judgment of how useful the individual scorer may find the proposed alternate use. If a participant provides a response that is not the same as the original use provided with the object or a repeat response, but the response does not make sense as an alternate use (e.g. for the AUT object of comb -> “potato”), it will not be accounted as *appropriate*.
- For *Detail*: To establish a standard criteria for scoring between 0 and 5, a score of 0 is given for no detail or elaboration given (i.e. A simple statement of the name of the new use, probably a noun;

e.g. for the AUT object of Button -> “wheel”). Scores of 1 through 5 should be given for combinations of specifics for persons, activities, object names (besides the name of the source AUT object), and contexts provided in the response. (e.g. Button -> “wheel for a toy car” would score 1, Button -> “wheel for my niece’s toy car when she plays with my cousin” would be 3). Responses that would garner a score of 5 would include at least five descriptive aspects.

- For *Flexibility*: This subscale is about counting

“...changes in direction of thinking when one is not instructed to do so, or need not do so...

The score for flexibility is the number of times that [the participant] shifts from one category of uses to another... A number of things belong to the same class because they have one or more attributes in common.” (Guilford, 1975)

If the rater thinks that a response belongs to a different class of objects than the previous response, then it is counted as a new category. This is by far the most individually subjective of the five subscales.

4.8.1 Inter-rater reliability

I also scored a randomly-selected subset of responses to compare with the rater’s scores in order to assess reliability and ensure a common understanding of the scoring guidelines early in the scoring process. A portion of responses from 13 of the 65 participants were compared to calculate inter-rater reliability. Reliability was high ($\alpha > 0.8$) on all four subscales (Cronbach’s α for *fluency* = 0.981, *appropriateness* = 0.994, *detail* = 0.836, *flex* = 0.905), so after a brief discussion clarifying further the criteria for the *detail* subscale, scoring by the rater continued to completion.

4.9 Scoring originality

Originality can only be scored once the entire body of responses has been evaluated with repeat, non-alternate, and inappropriate responses removed. Also, because *originality* is scored by comparing a

single response to all other responses given for an object by *all* participants, no external rater is required – comparison and point assignment is based on the frequency of a uses occurrence and is relatively objective. Scoring *originality* from spoken English does necessitate a subjective conversion of complex or vague statements into concise, comparable uses, but this process was not undertaken by the rater.

In order to score *originality* by comparing the frequency of specific alternate uses the uses must be comparable both within a participants body of responses and between participants. While most published creativity research using the AUT does not outline exactly how this is done with written AUT responses, previous creativity research has established a method for transforming a verbally-stated alternate use into an essential “gist”, which can then be compared to other “gisted” responses (Resse at al., 2001, p 494). I have not seen any research specifically addressing the difference between verbal and written AUT responses when scoring for originality, but I think that the language used in verbal AUT responses is much more elaborate and varied than the language used in written AUT responses. During experimental sessions I observed that participants attempting to think divergently while speaking aloud tended to use speech with numerous pauses, corrections, and impromptu elaborations. It is likely that written AUT responses do not need to be transformed to be counted and compared for originality scoring as written English is usually more tersely and concisely composed than impromptu spoken English.

This process of “gisting” involves re-stating a use as a standardized categorical object. For example, a verbal response of “burn them for fires or for starting fires” for the AUT object of newspaper would be gisted to “fuel”, as would “as fire starter by ripping it up into shreds” and “burn it and use it for warmth”. I gisted the alternate uses (3877 responses) for *originality* scoring only and counted the frequency of each specific gist given for an object, assigning 3 points for gists given by three or fewer participants, 2 points for gists given by four to six participants, and 1 point for gists given by seven to ten

participants. (The number of participants responding to point ratio is set along the 5%, 10% and 15% thresholds as previously outlined. $0.05 * 65$ participants = 3.25, or 3 participants, $0.1 * 65 = 6.5$, or 6 participants, $0.15 * 65 = 9.75$, or 10 participants.)

4.10 *Preparing scores for analysis*

Fluency, appropriateness, flexibility and originality scores for each use were summed to provide a total subscale score per object per participant, and detail scores were averaged for each object per participant. After removing the scores for the first three AUT objects (button, soap, and paper clip), these per object per participant scores were averaged to provide a mean subscale score for each participant. (The first three objects were removed to mimic Shobe et al's removal of the first five AUT object scores from their analysis as a five minute warm up buffer. Because I included the Utah teapot as an untimed interface and divergent thinking warm up object and also provided additional clarifying instruction between the teapot interaction and the main Alternate Uses section, only three of the one-minute AUT object scores were to be removed to provide approximately 5 minutes of warm-up time for each participant.) These mean subscale scores for each participant comprise the main body of data used for statistical analysis.

4.11 *Statistical Analysis Method – Handedness and English Fluency*

Although all 65 participants self-identified as fluent English speakers, I observed during some experimental sessions suggested that some participants struggled with spoken English in ways that most likely inhibited their ability to express their alternate uses for task objects. For example, several participants consistently provided grammatically-incorrect one or two word descriptions for alternate uses after lengthy pauses, such as “For beautiful... [long pause]... see 3-D movies” for the AUT object of glasses. Knowing that some SIAT students claim spoken English fluency but have great difficulty with written and spoken English (from my personal experience with the SIAT student population as a

teaching assistant), I included the FAS test as part of the session protocol in order to provide data to confirm or reject self-reports of English fluency. Unfortunately, normalized FAS scores from Tombaugh et al (1999) do not include a definitive cut-off for FAS fluency scores to be considered verbally fluent (e.g. scores above some number are considered fluent, scores below are not) – rather, they provide a rich description of verbal fluency as measured by the FAS test, stratified by educational experience and age group. In order to provide a second measure of English fluency to check FAS scores against, I tagged each participant with a “Face fluency” flag (yes/no) by listening through several random audio samples from each participant’s set of AUT response recordings. Graphing the “yes/no” Face fluency groups by FAS scores (figure 4.1) reveals that the “no Face fluency” group FAS scores are clustered below the 30th percentile of FAS scores (FAS scores under 38) for their age group and education level (13 to 21 years of education, ages 16 to 59 years). The graph also reveals a particular subgroup with scores in the lowest 10th percentile (FAS scores less than 30). However, there are also participants in the “yes Face fluency” group who score below the 30th and 10th percentile.

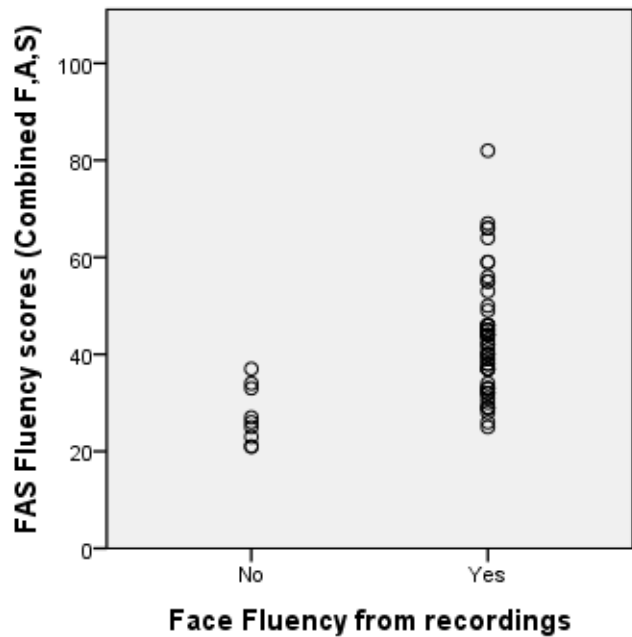


Figure 4.1 - Scatterplot of face fluency by FAS fluency scores.

There is evidence from both the FAS scores and Face fluency flag that some participants are not “as fluent” in spoken English as other participants. This is problematic because participants with low verbal English fluency have a reduced ability to express aloud alternate uses during the computerized AUT. However, there is no clear cut off for FAS scores which can be used to objectively identify participants as non-fluent even when considered with Face fluency grouping. For example, if a participant with an FAS score below 40 who was tagged as “no Face fluency” is removed, why is a participant with an FAS score below 40 who was tagged as “yes Face fluency” not removed? Consultation with my advisor and a professional statistician indicated that my subjective assessment of Face fluency alone was not an objective enough measure to exclude participant scores from analysis. However, the clustering of Graphing FAS scores by AUT *fluency* scores with the “no Face fluency” highlighted (figure 4.2) provides further evidence that there is a relationship between FAS score, Face fluency, and AUT fluency. In section 5.3.3 I analyse the correlation between FAS score, Face fluency, and AUT fluency and discuss the implications of this relationship in section 6.3.

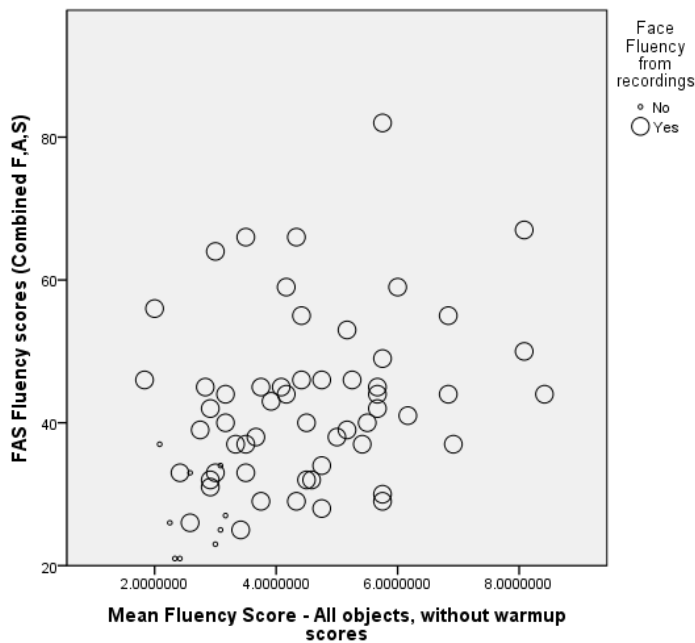


Figure 4.2 - FAS Score by AUT fluency with Face Fluency group indicated.

4.12 Statistical Analysis – Alternate Uses Subscales

4.12.1 Normalcy and homogeneity of variance

Continuing with the entire body of participants in the dataset for statistical analysis, I ran statistical tests to check for normalcy and homogeneity of variance in order to determine the proper statistical comparison of means for AUT scores and handedness groups. The Shapiro-Wilk test of normality (chosen for its sensitivity to detecting non-normal distributions with small sample sizes) shows significant results (indicating a non-normal distribution) for *fluency* scores for the mouse interface group with both strong and mixed hand subgroups integrated ($p < 0.05$, see table 4.1) and for the strong-handed participants only ($p < 0.05$, see table 4.2). *Appropriateness* scores for the mouse group (strong and mixed hand groups integrated) also were significantly non-normal ($p < 0.05$, see table 4.1), and *originality* scores for all participants using mouse and unimanual multitouch interfaces ($p < 0.01$ for both mouse and unimanual multitouch – see table 4.1) and strong handed participants only ($p < 0.001$ for mouse and $p < 0.01$ for unimanual multitouch – see table 4.2) were significantly non-normal as well.

Tests of Normality - Hand groups Integrated (strong + mixed)					Tests of Normality - Strong handed only				
	Interface style	Shapiro-Wilk				Interface style	Shapiro-Wilk		
		Statistic	df	Sig.			Statistic	df	Sig.
Mean Fluency Score	Mouse	.890	22	.019	Mean Fluency Score	Mouse	.896	19	.041
	Uni	.977	21	.868		Uni	.958	14	.687
	Bi	.930	22	.125		Bi	.954	15	.592
Mean Appro. Score	Mouse	.896	22	.025	Mean Appro. Score	Mouse	.902	19	.053
	Uni	.980	21	.931		Uni	.958	14	.697
	Bi	.933	22	.139		Bi	.953	15	.568
Mean Detail Score	Mouse	.944	22	.237	Mean Detail Score	Mouse	.940	19	.262
	Uni	.981	21	.938		Uni	.977	14	.953
	Bi	.948	22	.288		Bi	.944	15	.438
Mean Flexibility Score	Mouse	.951	22	.337	Mean Flexibility Score	Mouse	.943	19	.298
	Uni	.948	21	.309		Uni	.913	14	.176
	Bi	.915	22	.061		Bi	.919	15	.187
Mean Originality Score	Mouse	.800	22	.001	Mean Originality Score	Mouse	.756	19	.000
	Uni	.840	21	.003		Uni	.815	14	.008
	Bi	.921	22	.080		Bi	.968	15	.826

Table 4.1 and Table 4.2 - Shapiro-Wilk tests for normalcy by interface style.

As several of my hypotheses involve comparing means between strong and mixed-handed participants (H3 and H4) within individual interface styles, I also ran Shapiro-Wilk tests on handedness group data distribution by AUT subscale for each interface style group. *Fluency* scores for strong-handed participants with unimanual multitouch and mouse interface styles combined and mouse interface on its own tested as non-normal ($p < 0.05$, see tables 4.3 and 4.4). *Appropriateness* scores for strong-handed participants with combined unimanual multitouch and mouse group scores were also non-normal ($p < 0.05$, see table 4.3), as well as *originality* scores for strong-handed groups within unimanual and mouse interface styles ($p < 0.001$ for combined unimanual and mouse as well as mouse only, $p < 0.01$ for unimanual only – see tables 4.4 and 4.5).

Tests of Normality - mouse + unimanual multitouch Integrated					Tests of Normality - Mouse Interface only				
	Handedness Strong vs Mixed	Shapiro-Wilk				Handedness Strong vs Mixed	Shapiro-Wilk		
		Statistic	df	Sig.			Statistic	df	Sig.
Mean Fluency Score	Mixed	.957	10	.753	Mean Fluency Score	Mixed	.997	3	.893
	Strong	.933	33	.041		Strong	.896	19	.041
Mean Appro. Score	Mixed	.964	10	.825	Mean Appro. Score	Mixed	.998	3	.910
	Strong	.935	33	.048		Strong	.902	19	.053
Mean Detail Score	Mixed	.962	10	.806	Mean Detail Score	Mixed	.901	3	.389
	Strong	.985	33	.921		Strong	.940	19	.262
Mean Flexibility Score	Mixed	.944	10	.593	Mean Flexibility Score	Mixed	.995	3	.859
	Strong	.945	33	.095		Strong	.943	19	.298
Mean Originality Score	Mixed	.904	10	.241	Mean Originality Score	Mixed	.972	3	.681
	Strong	.779	33	.000		Strong	.756	19	.000

Table 4.3 and Table 4.4 - Shapiro-Wilk tests for normalcy by hand group.

Tests of Normality - Unimanual multitouch interface only				
	Handedness Strong vs Mixed	Shapiro-Wilk		
		Statistic	df	Sig.
Mean Fluency Score	Mixed	.875	7	.206
	Strong	.958	14	.687
Mean Appro. Score	Mixed	.880	7	.226
	Strong	.958	14	.697
Mean Detail Score	Mixed	.950	7	.727
	Strong	.977	14	.953
Mean Flexibility Score	Mixed	.932	7	.570
	Strong	.913	14	.176
Mean Originality Score	Mixed	.945	7	.682
	Strong	.815	14	.008

Table 4.5 - Shapiro-Wilk tests for normalcy by hand group continued.

Levene’s tests for homogeneity of variance found no significant difference in variance by interface style across all Alternate Uses Task subscales for both hand groups (integrated) and within strong-handed participants on their own. Leven’s test could not be run on AUT subscales by interface style within the mixed-handed group and by hand group within the mouse interface group due to highly unequal group numbers (SPSS error: “A spread vs. level plot is not provided because the median and/ or interquartile range is not defined, using the HAVERAGE method...”). Levene’s tests run on AUT scores by hand group for unimanual and bimanual multitouch interface styles also found no significant differences in variance except for *originality* scores of bimanual multitouch participants ($p < 0.01$, see table 6) – in other words, the distributions of *originality* scores for strong-handed participants vs. mixed-handed participants assigned to the bimanual multitouch condition have significantly unequal variance.

Test of Homogeneity of Variance - Bimanual only by Hand					
		Statistic	df1	df2	Sig.
Mean Originality Score	Based on Mean	8.308	1	20	.009
	Based on Median	3.118	1	20	.093
	Based on Median and with adjusted df	3.118	1	12.540	.102
	Based on trimmed mean	7.861	1	20	.011

Table 4.6 - Levene's test on *originality* variance between hand groups within participants assigned to the bimanual interface.

4.12.2 Appropriate statistical comparisons

With the results of these tests in mind, comparing means to test H1 (similarity in *flexibility* and *originality* between mouse and unimanual multitouch interface groups) will require two different statistical approaches. To compare means for the *flexibility* scores a t-test is appropriate, but since *originality* scores for these two interface groups are not normally distributed, the non-parametric Mann-Whitney U is a more accurate (and more conservative) test to compare means for *originality*. The appropriate statistical test for H2 (differences in *flexibility* and *originality* for strong-handed participants between bimanual and both unimanual multitouch and mouse interface groups) depends on several factors: If H1 is confirmed, the unimanual multitouch and mouse interface *flexibility* and *originality* scores can be combined into “non-bimanual” scores and compared to *flexibility* bimanual scores via a t-test and *originality* scores via a Mann-Whitney’s U (integrated mouse and unimanual *originality* scores are significantly non-normal – table 3). If H1 is not confirmed, H2 will be tested via an ANOVA for *flexibility* and a Kruskal-Wallis test comparing *originality*, with a post-hoc test (Tukeys) to pinpoint which interface styles differ significantly if a significant difference is detected.

Although no violations of normalcy were detected for the *flexibility* and *originality* subscales between strong and mixed-handed participants assigned to the bimanual interface, testing H3 will require a t-test

without the assumption of unequal variance (table 6), which is less sensitive to differences between means than the traditional t-test which assumes equal variance between groups.

As testing H4 requires comparing means across all AUT subscales between hand groups (strong and mixed) for mouse interface participants and unimanual interface participants, the t-test will be used to compare means for *detail* and *flexibility* within combined unimanual multitouch and mouse participants (table 3), for *appropriateness*, *detail* and *flexibility* within mouse participants (table 4.4), and for all subscales within unimanual multitouch participants (table 4.5). Mann-Whitney U will be used to compare *fluency* scores for combined mouse + unimanual interface groups (table 4.3), *fluency* scores in the mouse group (table 4.4), *appropriateness* scores for the combined mouse + unimanual interface groups (table 4.3), and *originality* scores between hand groups across all (mouse + unimanual multitouch, mouse, and unimanual multitouch) interface groups (tables 4.3, 4.4 and 4.5).

H5 involves similar comparison of means to H1 (comparing between mouse and unimanual multitouch groups within each hand group) but tests Alternate Use Task subscales which H1 does not (*Fluency*, *appropriateness*, and *detail*). Comparisons of *detail* scores between mouse and unimanual groups within the combined hand data will be done via a t-test, while *fluency* and *appropriateness* scores will be compared between mouse and unimanual via Mann-Whitney's U (table 1). Comparisons of *fluency* scores between mouse and unimanual interface groups within the strong-handed only subgroup will be done via Mann-Whitney's U as well, with *appropriateness* and *detail* being compared via a t-test (table 2). A t-test will be used within the mixed-handed only subgroup to compare *fluency*, *appropriateness*, and *detail* scores for mouse and unimanual interface groups (none of the subscales within this hand subgroup violated normality according to Shapiro-Wilk).

4.13 Qualitative Observations

While facilitating the experimental sessions for my study I took notes on participant comments and behaviours that either were consistent across a large number of participants, or that were highly unique to an individual participant's session. Details of these observations will be reported in Chapter 5 with the quantitative analysis and discussed in Chapter 6 with the quantitative results.

CHAPTER 5: RESULTS

5.1 Overview

To test my five hypotheses from Chapter Three I performed statistical analyses on Alternate Uses Task subscales grouped by combinations of interface style (mouse, unimanual multitouch, and bimanual multitouch) and handedness group (strong-handed and mixed-handed). In Chapter Four I discussed testing these data to determine the appropriate inferential statistical methods to use for hypothesis testing. In this chapter I report the results of descriptive and inferential statistical analysis for each hypothesis as well as themes from observations noted during my experimental sessions.

5.2 Results for Hypotheses

5.2.1 Hypothesis One: *Flexibility* and *Originality* within Mouse and Unimanual Multitouch by Interface Style

H1: *Flexibility* and *originality* scores from both strong and mixed-handed participants using the unimanual multitouch interface will be the same as scores from strong and mixed-handed participants using the mouse interface.

Based on Shobe et al. (2009) I predicted that *flexibility* and *originality* scores for the two unilateral interface styles (mouse and unimanual multitouch) would be similar across hand groups. Although I predicted similarity across hand groups for both subscales in a single hypothesis form Chapter Three, I have separated *flexibility* and *originality* predictions from H1 into two sub-hypotheses (H1a and H1b) in order to clarify the presentation of my hypothesis testing. (This pattern of separation into sub-hypotheses for clarity purposes is continued throughout this chapter.)

H1a: *Flexibility* scores from both strong and mixed-handed participants using the unimanual multitouch interface will be the same as scores from strong and mixed-handed participants using the mouse interface.

A t-test comparing *flexibility* means for unimanual multitouch ($M=3.3$, $SD=1.2$, $n=21$) and mouse ($M=3.3$, $SD=1.0$, $n=22$) interface groups with both strong and mixed handed groups integrated found no significant difference ($t(41) = 0.145$, $p = 0.885$). A t-test comparing *flexibility* means for strong-handed unimanual multitouch ($M_{strong}=3.4$, $SD=1.3$, $n=14$) and mouse ($M_{strong}=3.2$, $SD=0.9$, $n=19$) interface groups found no significant difference ($t(31) = -0.445$, $p = 0.659$), as did a t-test comparing mixed-handed unimanual multitouch ($M_{mixed}=3.0$, $SD=1.1$, $n=7$) and mouse ($M_{mixed}=4.0$, $SD=1.6$, $n=3$) interface groups ($t(8) = 1.125$, $p = 0.293$). When interpreting mean *flexibility* scores keep in mind that there is no “maximum” score – these means are averages of number of different categories a participant covered in a set of responses for an AUT object.

H1b: *Originality* scores from both strong and mixed-handed participants using the unimanual multitouch interface will be the same as scores from strong and mixed-handed participants using the mouse interface.

A Mann-Whitney’s U comparison of *originality* ranks for unimanual multitouch ($M_{rank}=24$, median=3.5, IQR=1.9, $n=21$) and mouse ($M_{rank}=21$, median=2.6, IQR=2.1, $n=22$) interface groups with both strong and mixed handed groups integrated found no significant difference ($U=199$, $p=0.44$). A Mann-Whitney’s U comparison of *originality* ranks for strong-handed unimanual multitouch ($M_{rank}=17$, median=2.8, IQR=2.8, $n=14$) and mouse ($M_{rank}=17$, median=2.6, IQR=2.0, $n=19$) interface groups also found no significant difference ($U=127$, $p=0.84$). A t-test comparing *originality* means for mixed-handed unimanual multitouch ($M_{mixed}=3.8$, $SD=0.93$, $n=7$) and mouse ($M_{mixed}=4.4$, $SD=2.7$, $n=3$) interface groups found no significant difference ($t(8) = 0.546$, $p = 0.6$). When interpreting results of non-parametric

statistics like Mann-Whitney U's a higher rank indicates a higher central tendency (reported as median in this case) and inter-quartile ranges (IQR) indicate variability within the dataset.

These results suggest that H1 is confirmed: whether compared with hand groups integrated (strong + mixed) or with hand groups separated and analysed individually, there is no significant difference between means on the *flexibility* and *originality* subscales for participants using the mouse or unimanual multitouch interface. Because scores on these subscales between the two unilateral interfaces are not significantly different, these scores will be combined into a single "unilateral interface style" group for testing H2.

5.2.2 Hypothesis Two: *Flexibility* and *Originality* for Strong-Handed Participants by Interface Style

H2: *Flexibility* and *originality* scores from strong-handed participants using the bimanual multitouch interface will be higher than scores from strong-handed participants using the unimanual multitouch and mouse interfaces.

H2 is intended to test if Shobe et al's findings of increased *flexibility* and *originality* scores for strong-handed participants who completed a bilateral body movement exercise transfer to bimanual hand motion during bimanual multitouch display interaction. Recall that Shobe et al found no difference in scores on these subscales from mixed-handed participants when comparing bilateral eye movement and control groups, hence H2's predicted difference would hold only for strong-handed participants in my study. Statistical comparisons for testing H2 use the combined "unilateral interface style" scores (combined mouse and unimanual multitouch *flexibility* and *originality* scores) from H1. The combined "unilateral interface style" *flexibility* and *originality* scores were checked for normalcy and homogeneity of variance - *flexibility* was found to be normally distributed via Shapiro-Wilk while *originality* was not. Both *flexibility* and *originality* "unilateral interface style" subscales passed Levene's test for homogeneity of variance.

H2a: *Flexibility* scores from strong-handed participants using the bimanual multitouch interface will be higher than scores from strong-handed participants using the unimanual multitouch and mouse interfaces.

A t-test comparing *flexibility* means for strong-handed bimanual ($M=3.2$, $SD=0.92$, $n=15$) and combined unilateral ($M=3.3$, $SD=1.1$, $n=33$) interface groups did not find a significant difference ($t(46) = 0.204$, $p = 0.839$).

H2b: *Originality* scores from strong-handed participants using the bimanual multitouch interface will be higher than scores from strong-handed participants using the unimanual multitouch and mouse interfaces.

A Mann-Whitney's U comparison of strong-handed *originality* ranks for bimanual multitouch ($M_{\text{rank}}=24$, median=2.6, IQR=1.5, $n=15$) and unilateral ($M_{\text{rank}}=25$, median=2.7, IQR=2, $n=33$) found no significant difference ($U=234.5$, $p=0.77$). These results provide no evidence to support H2 – *flexibility* and *originality* scores for strong-handed participants do not significantly differ by interface style.

5.2.3 Hypothesis Three: *Flexibility* and *Originality* for Bimanual Multitouch participants by Handedness

H3: *Flexibility* and *originality* scores from strong-handed participants using the bimanual multitouch interface will be the same as scores from mixed-handed participants using the bimanual multitouch interface.

Shobe et al found that *flexibility* and *originality* scores for participants who completed the bilateral eye movement exercises did not differ between strong-handed and mixed-handed participants – that is, they concluded that strong-handed *flexibility* and *originality* scores were boosted to mixed-handed levels (which are typically higher) by the BEM exercise. Testing H3 checks to see if this boosting of

flexibility and *originality* scores for strong-handed participants who have undergone bilateral body movement by using the bimanual multitouch interface carries through from Shobe et al's findings.

H3a: *Flexibility* scores from strong-handed participants using the bimanual multitouch interface will be the same as scores from mixed-handed participants using the bimanual multitouch interface.

A t-test comparing *flexibility* means for strong ($M=3.2$, $SD=0.92$, $n=15$) and mixed-handed ($M=3.1$, $SD=1.2$, $n=7$) participants using the bimanual interface found no significant difference ($t(20) = 0.178$, $p = 0.861$).

H3b: *Originality* scores from strong-handed participants using the bimanual multitouch interface will be the same as scores from mixed-handed participants using the bimanual multitouch interface.

A t-test for comparing *originality* means for strong ($M=2.8$, $SD=1.2$, $n=15$) and mixed-handed ($M=3.9$, $SD=2.3$, $n=7$) participants using the bimanual interface found no significant difference ($t(20) = 0.178$, $p = 0.861$). The more conservative unequal variance version of the t-test was used for *originality* as a Leven's test for homogeneity of variance indicated variation between strong and mixed-handed participants was significantly different ($F=8.3$, $p=0.09$). These results provide evidence confirming H3: *Flexibility* and *originality* scores among participants assigned to the bimanual interface do not differ by hand group (strong vs mixed).

5.2.4 Hypothesis Four: All AUT subscales for Mouse and Unimanual Multitouch participants by Handedness

H4: Scores across all AUT subscales will be higher for mixed-handed participants using unimanual multitouch and mouse interfaces than strong-handed participants using unimanual multitouch and mouse interfaces.

Shobe et al found that mixed-handed participants scored higher on all five Alternate Uses Task subscales (*fluency, appropriateness, detail, flexibility, and originality*) for control (non-bilateral eye movement) participants. H4 proposes that this will also be the case for the unilateral interface styles – mouse and unimanual multitouch participants who are mixed handed are predicted to have higher scores than strong-handed participants across all the AUT subscales. To avoid a potentially exhausting account of comparisons for each of the five AUT subscales, descriptive and inferential statistics used to test H4 are tabulated in table 5.1.

AUT subscale		central tendency	variance	statistic	significance
<i>fluency</i>	mixed	M _{rank} =24, median=4.6	IQR=2.4	Mann-Whitney U=144	p=0.546
	strong	M _{rank} =21, median=4.3	IQR=2.2		
<i>appropriateness</i>	mixed	M _{rank} =24, median=4.6	IQR=2.5	Mann-Whitney U=144	p=0.536
	strong	M _{rank} =21, median=4.3	IQR=2.2		
<i>detail</i>	mixed	M=1.3	SD=0.7	t(41)=-0.551	p=0.585
	strong	M=1.2	SD=0.56		
<i>flexibility</i>	mixed	M=3.3	SD=1.2	t(41)=-0.108	p=0.915
	strong	M=3.3	SD=1.1		
<i>originality</i>	mixed	M _{rank} =28, median=3.8	IQR=1.5	Mann-Whitney U=107	p=0.092
	strong	M _{rank} =20, median=2.7	IQR=2.0		

Table 5.1 – Comparisons between mixed (n=10) and strong-handed (n=33) participants using unilateral interfaces for each AUT subscale.

Comparing AUT subscale scores between strong and mixed handed participants for combined mouse and unimanual multitouch scores reveals no significant differences. Comparisons between mixed and strong-handed participants for the separated unilateral interface groups (mouse and unimanual

multitouch) are tabulated in tables 5.2 and 5.3. These comparisons revealed a significant difference between mean mixed and strong-handed *detail* scores for the mouse interface at the $p < 0.05$ level, but no other significant score differences were found.

AUT subscale		central tendency	variance	statistic	significance
<i>fluency</i>	mixed	$M_{\text{rank}}=14$, median=5.3	IQR= n/a	Mann-Whitney $U=20$	p=0.389
	strong	$M_{\text{rank}}=11$, median=4.1	IQR=1.8		
<i>appropriateness</i>	mixed	M=5.3	SD=2.5	t(20)=-1.137	p=0.269
	strong	M=4.2	SD=1.5		
<i>detail</i>	mixed	M=1.8	SD=0.52	t(20)=-2.144	p=0.044
	strong	M=1.1	SD=0.75		
<i>flexibility</i>	mixed	M=4.0	SD=1.6	t(20)=-1.255	p=0.224
	strong	M=3.2	SD=0.9		
<i>originality</i>	mixed	$M_{\text{rank}}=14$, median=3.9	IQR= n/a	Mann-Whitney $U=20$	p=0.415
	strong	$M_{\text{rank}}=11$, median=2.6	IQR=2.0		

Table 5.2 – Comparisons between mixed (n=3) and strong-handed (n=19) participants using the mouse interface for each AUT subscale. Note that the small group size of mixed-handed mouse participants limits non-parametric statistical approaches.

AUT subscale		central tendency	variance	statistic	significance
<i>fluency</i>	mixed	M=4.3	SD=1.5	t(19)=0.231	p=0.82
	strong	M=4.5	SD=1.7		
<i>appropriateness</i>	mixed	M=4.3	SD=1.5	t(19)=0.223	p=0.826
	strong	M=4.5	SD=1.7		
<i>detail</i>	mixed	M=1.1	SD=0.60	t(19)=0.832	p=0.416
	strong	M=1.3	SD=0.61		
<i>flexibility</i>	mixed	M=3.0	SD=1.1	t(19)=0.599	p=0.556
	strong	M=3.4	SD=1.3		
<i>originality</i>	mixed	$M_{\text{rank}}=13$, median=3.7	IQR=1.0	Mann-Whitney $U=35$	p=0.279
	strong	$M_{\text{rank}}=10$, median=2.8	IQR=2.8		

Table 5.3 – Comparisons between mixed (n=7) and strong-handed (n=14) participants using the unimanual interface for each AUT subscale.

These results do not provide evidence supporting H4 – mixed-handed participants using the mouse or unimanual multitouch interface did not score significantly higher on the AUT subscales (except for *detail* scores for participants using the mouse interface) than strong-handed participants.

5.2.5 Hypothesis Five: *Fluency, Appropriateness* and *Detail* within Mouse and Unimanual Multitouch by Interface Style

H5: *Fluency, appropriateness, and detail* scores from both strong and mixed-handed participants using the unimanual multitouch interface will be the same as scores from both strong and mixed-handed participants using the mouse interface.

Findings from HCI and cognitive psychology (including Shobe et al’s research) do not predict any difference on Alternate Uses Task performance due to differences in direct (“hand-on-screen”) or (“hand-off-screen”) interaction, which is reflected in the H5’s prediction of no score differences for *fluency, appropriateness, and detail* between mouse and unimanual multitouch participants. Testing this hypothesis is intended as an exploratory nudge into potential future research on differences between direct and indirect interaction.

H5a: *Fluency* scores from both strong and mixed-handed participants using the unimanual multitouch interface will be the same as scores from both strong and mixed-handed participants using the mouse interface.

A Mann-Whitney’s U comparison of *fluency* ranks for unimanual multitouch ($M_{\text{rank}}=23$, median=4.5, IQR=2.4, n=21) and mouse ($M_{\text{rank}}=22$, median=4.2, IQR=2.4, n=22) interface groups with both strong and mixed-handed groups integrated found no significant difference ($U=220$, $p=0.78$). A Mann-Whitney’s U comparison of *fluency* ranks for unimanual multitouch ($M_{\text{rank}}=18$, median=4.5, IQR=2.4, n=14) and mouse ($M_{\text{rank}}=16$, median=4.1, IQR=1.8, n=19) interface groups with for strong-handed participants

found no significant difference as well ($U=118$, $p=0.585$). A t-test comparing *fluency* means for unimanual multitouch ($M=4.3$, $SD=1.5$, $n=7$) and mouse ($M=5.4$, $SD=2.6$, $n=3$) interface groups for mixed-handed participants also found no significant difference ($t(8)=0.9$, $p=0.394$).

H5b: *Appropriateness* scores from both strong and mixed-handed participants using the unimanual multitouch interface will be the same as scores from both strong and mixed-handed participants using the mouse interface.

A Mann-Whitney's U comparison of *appropriateness* ranks for unimanual multitouch ($M_{\text{rank}}=23$, median=4.4, IQR=2.4, $n=21$) and mouse ($M_{\text{rank}}=22$, median=4.2, IQR=2.4, $n=22$) interface groups with both strong and mixed-handed groups integrated found no significant difference ($U=222$, $p=0.817$). A t-test comparing *appropriateness* means for unimanual multitouch ($M=4.5$, $SD=1.7$, $n=14$) and mouse ($M=4.2$, $SD=1.5$, $n=19$) interface groups for strong-handed participants found no significant difference as well ($t(31)=-0.389$, $p=0.693$). A t-test comparing *appropriateness* means for unimanual multitouch ($M=4.3$, $SD=1.5$, $n=7$) and mouse ($M=5.4$, $SD=2.5$, $n=3$) interface groups for mixed-handed participants also found no significant difference ($t(8)=0.879$, $p=0.405$).

H5c: *Detail* scores from both strong and mixed-handed participants using the unimanual multitouch interface will be the same as scores from both strong and mixed-handed participants using the mouse interface.

A t-test comparison of *detail* means for unimanual multitouch ($M=1.3$, $SD=0.6$, $n=21$) and mouse ($M=1.2$, $SD=0.59$, $n=22$) interface groups with both strong and mixed-handed groups integrated found no significant difference ($t(41)=-0.299$, $p=0.767$). A t-test comparing *appropriateness* means for unimanual multitouch ($M=1.3$, $SD=0.61$, $n=14$) and mouse ($M=1.1$, $SD=0.52$, $n=19$) interface groups for strong-handed participants found no significant difference as well ($t(31)=-1.176$, $p=0.248$). A t-test comparing *appropriateness* means for unimanual multitouch ($M=1.1$, $SD=0.6$, $n=7$) and mouse ($M=1.8$, $SD=0.75$,

n=3) interface groups for mixed-handed participants also found no significant difference ($t(8)=1.649$, $p=0.138$). These results provide evidence supporting H5.

5.3 Demographic Variables

Of all the demographic variables I collected as part of this research, only handedness was strongly predicted to have an effect on scores from the Alternate Uses Task. In order to explore possible effects of other demographic variables in AUT performance, I graphed each AUT subscale by gender, age, self-reported language background, and self-reported experience with mouse and multitouch interfaces and computer use.

5.3.1 Gender

Shobe et al initially detected a gender difference in *flexibility* and *originality* scores with males scoring slightly higher, but after performing a Bonferroni correction adjusted to $\alpha = 0.01$, they concluded that the difference were “spurious, and not significant”. Gender was balanced within each of my interface style groups (mouse: 11 female, 11 male; unimanual multitouch: 10 female, 11 male; bimanual multitouch: 12 female, 10 male) and roughly balanced between strong and mixed-handed participants overall (strong: 26 female, 22 male; mixed: 7 female, 10 male). Graphing AUT subscales by gender (figure 5.1) suggested that gender was not a significant factor for AUT scores in my research, and running each AUT subscale by gender via Mann-Whitney’s U confirmed that the relationship between gender and subscale rank was not significant.

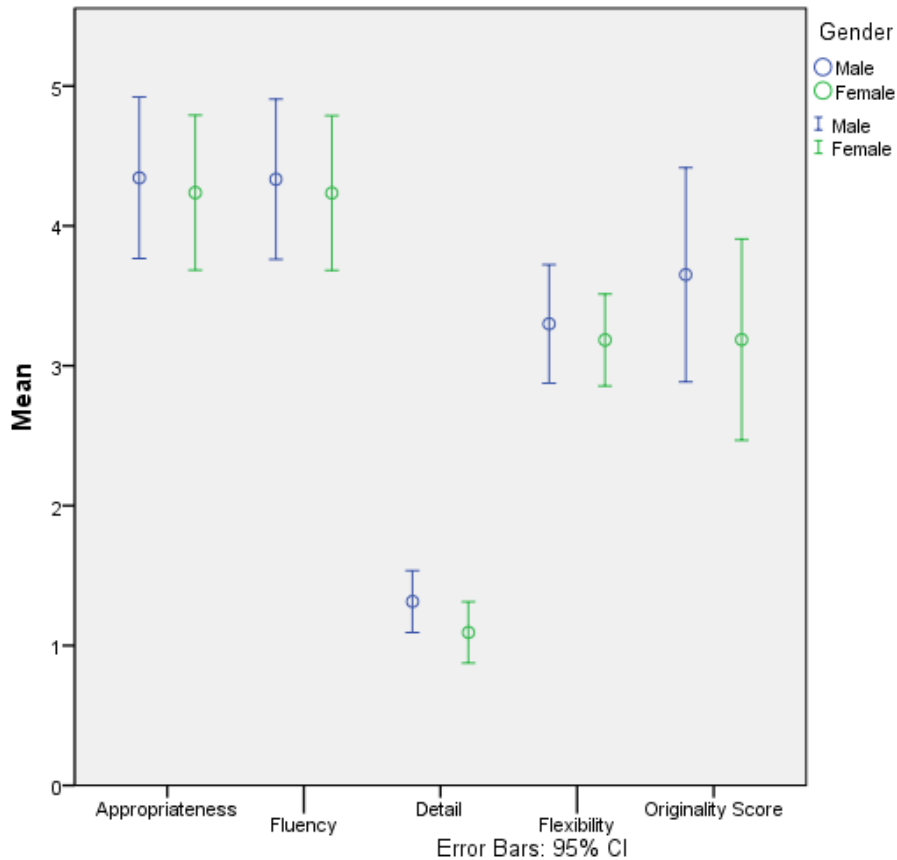


Figure 5.1 - AUT subscales by gender.

5.3.2 Age

Previous creativity research into divergent thinking has established that creative performance on tests like the Alternate Uses Task is highly influenced by age (Reese et al., 2001). Furthermore, Gilhooly et al's (2007) detailed research into mental strategies used during divergent thinking reveals that memory access of past experience is most likely the most common strategy used when participating in the Alternate Uses task. The distribution of age groups among my participants is shown in table 5.4

Age Group	Frequency
18 to 21	28
22 to 25	14
26 to 29	9
30 to 50	13
50+	1
Total	65

Table 5.4 – Age group distribution.

In order to explore the effect of participant age on AUT subscales in this research, I graphed the subscales by age group (figure 5.2). Graphing the subscales by age reveals a salient trend for age.

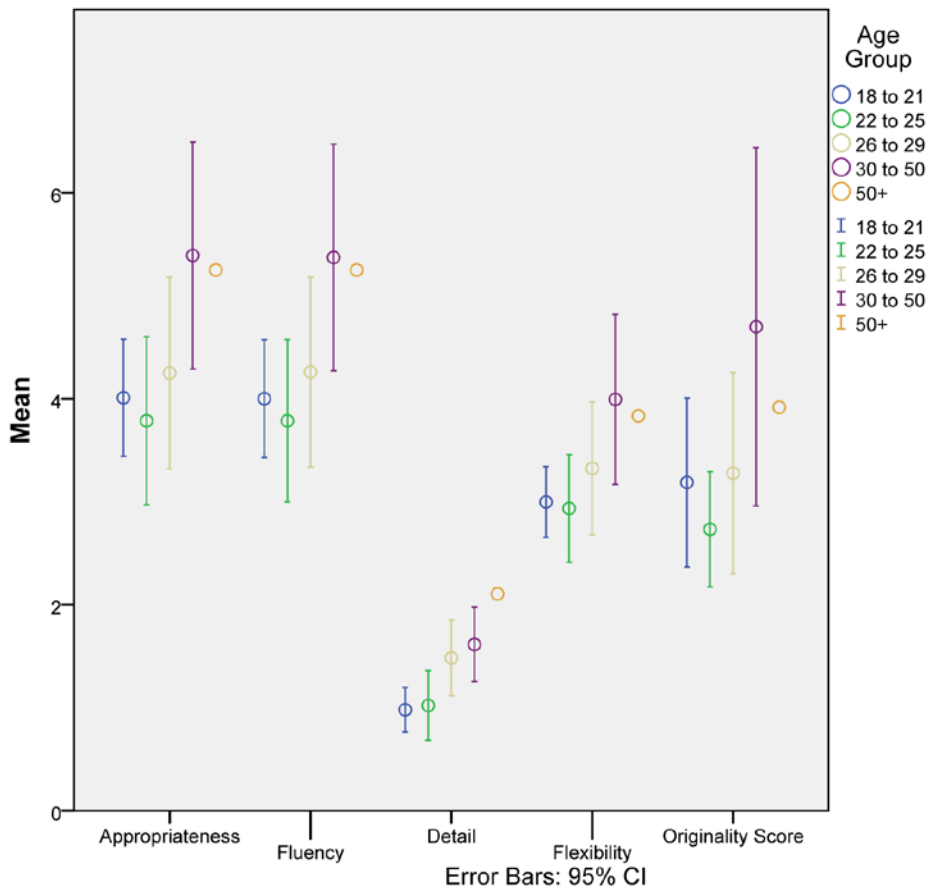


Figure 5.2 - AUT subscales by age group.

Performing a Kruskal-Wallis test on AUT subscales by age group identified a very significant ($p < 0.01$) age effect for *detail* $\chi^2(4, N = 64) = 14.037, p = 0.007$, but no significant age effect for any of the other AUT subscales.

5.3.3 Language Background

As previously discussed in Chapter Four, I anticipated that language proficiency (especially with spoken English) would be a factor in AUT performance for my study. Graphing AUT subscales by participant's self-report as native English-speakers (figure 5.3) reveals a stark difference in AUT scores by identification as a native English speaker.

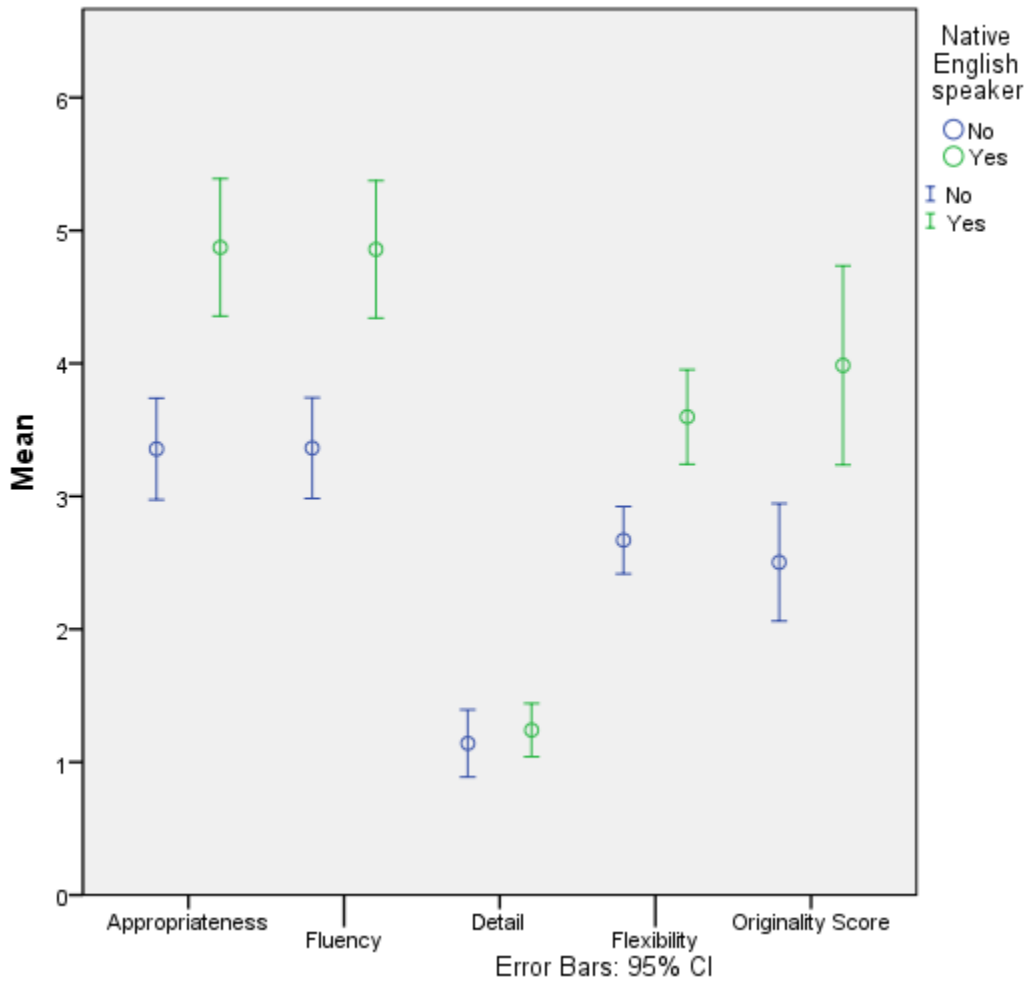


Figure 5.3 - AUT subscales by self-report as a native English speaker.

Mann-Whitney’s U tests for rank differences for each Alternate Uses Task subscale by native English speaking background (table 5.6) reveals a highly significant relationship for *fluency*, *appropriateness* and very significant relationship for *flexibility*, and *originality*. (Refer to table 5.5 for the specific rank differences for each subscale.)

Ranks

	Native English speaker	N	Mean Rank	Sum of Ranks
Appropriateness	No	25	21.80	545.00
	Yes	40	40.00	1600.00
	Total	65		
Fluency	No	25	21.94	548.50
	Yes	40	39.91	1596.50
	Total	65		
Detail	No	25	31.30	782.50
	Yes	40	34.06	1362.50
	Total	65		
Flexibility	No	25	22.86	571.50
	Yes	40	39.34	1573.50
	Total	65		
Originality Score	No	25	24.42	610.50
	Yes	40	38.36	1534.50
	Total	65		

Test Statistics^a

	Appropriateness	Fluency	Detail	Flexibility	Originality Score
Mann-Whitney U	220.000	223.500	457.500	246.500	285.500
Wilcoxon W	545.000	548.500	782.500	571.500	610.500
Z	-3.777	-3.730	-.573	-3.423	-2.894
Asymp. Sig. (2-tailed)	.000	.000	.567	.001	.004

a. Grouping Variable: Native English speaker

Tables 5.5 and 5.6 - results of mean rank analysis and Man-Whitney U for AUT subscales by native English speaking background.

Recalling the suggestive relationship between the other language-related demographic data (FAS score and “face-fluency”), I ran a non-parametric correlation (Spearman’s rho) to examine the relationship between native English background, FAS score, and “face-fluency” (table 5.7).

Correlations

			Face Fluency from recordings	Native English speaker	FAS Fluency scores (Combined F, A,S)
Spearman's rho	Face Fluency from recordings	Correlation Coefficient	1.000	.507**	.485**
		Sig. (2-tailed)	.	.000	.000
		N	65	65	65
	Native English speaker	Correlation Coefficient	.507**	1.000	.304*
		Sig. (2-tailed)	.000	.	.014
		N	65	65	65
	FAS Fluency scores (Combined F,A,S)	Correlation Coefficient	.485**	.304*	1.000
		Sig. (2-tailed)	.000	.014	.
		N	65	65	65

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 5.7 - Spearman's rho for Face fluency, native English speaking background, and FAS score.

The results of the correlation indicate a highly significant relationship between “face-fluency” and both native English background ($\rho = 0.507$, $p < 0.001$) and FAS score ($\rho = 0.485$, $p < 0.001$). Native English background is also significantly correlated to FAS score ($\rho = 0.304$, $p < 0.05$). Participants who identified as non-native English speakers were evenly distributed among the three interface style groups (8 in mouse, 9 in unimanual multitouch, and 8 in bimanual multitouch). Participants tagged as not Face fluent were not as evenly distributed among the interface styles (2 in mouse, 3 in unimanual multitouch, 4 in bimanual multitouch). A discussion of how these demographic results may have affected the results of my hypothesis testing is included in section 6.3.

5.3.4 Interface and Computer Experience

As part of the post-task questionnaire participants rated their experience with mouse use, multitouch use, and general computer use. Graphing the relationship between these self-reports and the AUT subscales does not reveal any suggestive trend. As most participants self-reported as both daily mouse and multitouch users, I did not explore any potential relationship between interface use background and AUT performance in my study.

5.4 Qualitative Observations

Notes from informal observations taken during the Alternate Use Task sessions for my study suggest two interesting approaches to generating alternate uses for AUT task objects.

First, I observed that some individuals would follow conceptual themes in as the generated new uses for the objects they were currently interacting with. For example, several participants would suggest costuming-related uses consistently for each object along with other uses. Other participants appeared to follow themes such as gardening, playing with children, and decoration of personal space. These thematic uses were often accompanied by detailed recounting by participants of their personal use of the AUT object for the recounted use.

Second, I observed what might be called “interaction-based” cuing for as participants generated new uses for the AUT objects. As participants would rotate and scale the virtual object, they would often link the change in viewing angle or size to new uses. For example, a participant scaling the button commented “Well, if it was this big and it floated you could use it to hold cups in a pool.” Another participant rotated the comb so that they could view the length of it and said “look at that edge... could be a ruler”. This “interaction-based” cuing was observed in the majority of study sessions, and was denoted as “scaling cue, rotation cue” in my observation notes.

CHAPTER SIX: DISCUSSION

6.1 Overview

This chapter discusses the results reported and analyzed in the previous chapter (Chapter Five) in order to clarify how my study has addressed the research questions put forward in Chapter Two. I begin with a discussion of the predicted boost for strong-handed participants using the bimanual interface in *flexibility* and *originality* scores in light of results from testing H1, H2 and H3. I then discuss the predicted difference between mixed-handed and strong-handed participants for the mouse and unimanual interface styles (H3, H4 and H5) as well how the results testing for differences between mouse and unimanual interface styles may apply to research into direct/indirect interaction. After discussing the results of the hypotheses testing from Chapter Five, I turn to the demographic data for my participant group in order to tease out the most prominent effects on divergent thinking measure by this study. Finally, I briefly discuss the qualitative observations from my facilitator notes and finish with implications of my research for interface design.

6.2 Discussion of Research Questions

6.2.1 Boosting *Flexibility* and *Originality* for Strong-handed participants through bimanual interaction

Does bimanual interaction affect divergent thinking in a similar way to bilateral eye movement?

Statistical testing did not find evidence to support the predicted difference on the *flexibility* and *originality* subscales between unimanual interaction and bimanual interaction for strong-handed participants (H2). This prediction was at the crux of my original research question which motivated this study – Does bimanual interaction affect divergent thinking in a similar way to bilateral eye movement? Although confirming the similarity of *flexibility* and *originality* scores between unimanual multitouch and

mouse participants (H1) provided a unified set of unimanual interaction data to compare against for testing this hypothesis, *flexibility* and *originality* scores for strong-handed participants across all three interaction style groups were found to be statistically similar. While rejecting H2 does not necessarily indicate that bimanual interaction does not affect divergent thinking in a similar way to bilateral eye movement, it strongly suggests that if there is a divergent thinking boost supported by bimanual interaction such a boost is minimal when compared to other divergent thinking factors. (This possibility is discussed in further detail in light of the analysis of age and language on AUT subscales later in section 6.3.) While finding evidence to support H3 (similarity in *flexibility* and *originality* scores for strong-handed and mixed-handed participants assigned to the bimanual interface style) could be interpreted as evidence of strong-handed divergent thinking ability being boosted to typically-higher mixed-handed levels, this interpretation must be rejected in light of evidence for equal AUT scores between mixed and strong handed participants across all three interface styles (i.e. rejecting H4). The possibility that bimanual interaction may not induce inter-hemispheric interaction in a similar way to bilateral eye movement is also a possible explanation for my findings from H2, although the higher trait IHI of mixed-handed participants should have been reflected in AUT scores (H4) if a lack of IHI boosting for strong-handed participants was the primary phenomena influencing AUT scores in my study. Another possibility is that all three interface styles caused bilateral eye movement similar to Shobe et al's BEM exercise. If the large display size used for the computerized AUT encouraged saccades that are similar to the deliberate horizontal eye movements Shobe et al used to induce higher IHI, then strong-handed *flexibility* and *originality* scores for participants using all three interface styles would be similar boosted as well.

In summary, I failed to find evidence that bimanual interaction affects divergent thinking in a similar way to bilateral eye movement as reported by Shobe et al (2009), however I also do not have evidence

to support the theory that bimanual interaction does not influence IHI in a similar way to bilateral eye movements.

6.2.2 Higher AUT performance for Mixed-hand participants compared to Strong-hand when using unimanual interfaces

Do mixed-handed users interacting with one-handed interfaces maintain greater divergent-thinking ability than strong-handed users with these interfaces?

Based on Shobe et al's report of higher AUT scores across all subscales for mixed-handed participants when compared to scores from strong-handed participants, I predicted a similar difference would be found among mixed-handed participants assigned to one of the two unilateral interfaces (mouse and unimanual multitouch). Although evidence was found to support this prediction on a single subscale (*detail*) within a specific handedness subgroup (mixed-hand) for a specific interface (mouse), this finding alone is not nearly enough to overcome the tests of all the other AUT subscales which did not find evidence to support H4. Shobe et al found the strongest evidence for higher mixed-handed divergent thinking performance when comparing scores within their control group (participants who did not complete the bilateral eye movement exercise), which prompted me to look for similar results among my unilateral groups. Testing H4 and finding no evidence to support it calls into question the sensitivity of the computerized Alternate Uses Task for detecting all but major differences in divergent thinking ability. Multiple divergent thinking studies have reported mixed-handed superiority in AUT scores, and the proposed mechanism for this advantage (inter-hemispheric interaction) is relatively well-understood. Besides the possibility that the computerized AUT is somehow less sensitive to divergent thinking differences than the paper AUT, it is also possible that factors stronger than handedness were influencing divergent thinking scores among my study population. (Again, this possibility is discussed in

further detail in the context of the effects of demographic variables on AUT subscales later in section 6.3.)

6.2.3 Divergent thinking changes affected by Direct vs. Indirect interaction

Are there differences between direct and indirect interaction that affect divergent thinking performance?

Although I am not aware of any research from cognitive psychology or HCI predicting aspects of divergent thinking affected by hands-on-screen or hands-off-screen (direct/indirect) interaction, AUT scores between participants using mouse and unimanual interface styles were tested to check for this possibility (H5). This research question was extremely exploratory in nature and was prompted more by the convenience of having an experimental design and dataset already set up to test other hypotheses (H1 through H4) which also allowed me to identify any and begin to explain unexpected differences in mouse and unimanual multitouch scores in terms of direct vs. indirect interaction. Confirming that all AUT subscales are similar across both one-handed interfaces (H1 and H5) does not provide evidence prompting further investigation into direct vs. indirect interaction difference that may affect divergent thinking.

6.3 Demographic variables affecting divergent thinking: Age and Language

Failing to find evidence to support bimanual support of divergent thinking (H2) and increased divergent thinking ability for mixed-handed participants (H4) could be interpreted as evident that some factor in my research design is not as sensitive to detecting differences in divergent thinking performance as Shobe et al's research design. The aspect of my research design which is the most different from Shobe et al's research is my research instrument, the computerized Alternate Uses Task. However in light of

evidence indicating a trend for age-dependant differences and a strong effect of language background in AUT performance in my dataset, it is also possible that high variability in my participant population overcame divergent thinking differences caused by mixed-handedness and bilateral body movement. The intent of my research design was to isolate the potential effects of handedness and hand use on divergent thinking; however analysis from Chapter Five indicates that language background was the strongest factor in Alternate Use Task scores. It is conceivable that the lack of evidence supporting mixed-handedness and bimanual superiority in divergent thinking is a result of confounding factors. Variability in verbal English fluency among my participants is especially problematic. Not only does lack of English fluency prevent a participant from accurately stating aloud any alternate uses they generate, it also may result in misunderstandings of task instructions and misidentification of handedness via the activity self-report used in the Edinburgh Handedness Inventory.

It is also worth noting that despite a large number of participants (relative to most HCI research), dividing 65 participants among three interface styles and two handedness groups often resulted in extremely unbalanced statistical comparisons. For example, the significant difference found between mixed and strong-handed participants' *detail* scores for mouse interaction involved comparing the mean *detail* score from 19 strong-handed participants against the mean *detail* score from only three mixed-handed participants. A group size of three participants is highly unlikely to be representative of "real-world" mixed-handed *detail* ability for any sort of computer interaction.

Comparing my participant group distribution to the participant demographics reported by Shobe et al provides some support to the idea that a more homogenous participant population aides in the detection of strong and mixed-handed differences in *flexibility* and *originality* scores. Shobe et al report that they carried out their study with 13 males and 49 females (n = 62), 30 of which scored as mixed-handed on the Edinburgh Handedness Inventory. These participants were randomly assigned between

two experimental groups: control (n = 30) and bilateral eye movement (n = 32). Although Shobe et al don't report the exact number of mixed and strong handed participants assigned to each group, it is likely that they their statistical comparisons between strong and mixed handed BEM participants were more balanced than my comparisons between strong and mixed handed participants. Their comparisons are also more likely to be sensitive to differences between strong and mixed-handed participants due to a greater number of mixed-handed participants in their study overall (32 for Shobe et al, 17 in my study). My comparisons also spread 65 participants between three interaction style groups, further diminishing group sizes and group balance in statistical testing. While Shobe et al do not report any language demographics or language effects in their study, they do report a similar age distribution to my participant group (18 to 56 years).

In designing a research study that can be completed within the context of a Master's thesis, I have made some assumptions that could also contribute to differences in divergent thinking measurement ability compared to Shobe et al. First, I have assumed that the computerized AUT created for this study is equal to the paper-administered AUT in its ability to elicit divergent thinking responses. Second, I had assumed that the three interface styles (mouse, unimanual multitouch, and bimanual multitouch) differ in their influence on divergent thinking primarily in terms of inter-hemispheric-interaction (IHI), not other (potentially confounding) phenomena which may affect divergent thinking. Third, I have assumed that using both hands in the bimanual interface condition will boost IHI (and consequently divergent thinking) enough to be measureable when compared to divergent thinking performance from the other interface style groups, similarly to bilateral eye movement for Shobe et al. Ideally each of these assumptions should be tested as part of a longer and more involved research program into the potential effects of bimanual interaction on divergent thinking.

6.4 Object Representation and Divergent Thinking Strategies

Qualitative observations from my experimental sessions have provided both confirmation of previous divergent thinking research and insight into underexplored aspects of divergent thinking support. The identification of participants following “themes” in their Alternate Use responses is consistent in light of research into divergent thinking strategies (Gilhooly et al., 2007). This research identifies memory-access as the first and most common mental strategy used in divergent thinking tasks and also identifies analogical thinking (this object is like this other object) and mental disassembly (the breakdown of an object into sub-objects or materials with which the thinker is familiar) as a common divergent thinking strategies. My observations that participants are likely leveraging memories and domain-specific knowledge to generate new uses for AUT objects is consistent with this research.

In my review of creativity research and literature examining divergent thinking I have encountered minimal consideration of the influence of the representational form of divergent thinking prompts on divergent thinking responses (Smith et al 1993 is an notable exception). Creativity researchers have examined the effects of different representational forms on mental combination in creativity tasks (Verstijnen et al., 1998; Finke, 1990), but I am not aware of any research examining the impact of virtual objects (or physical objects, for that matter) on divergent thinking ability in the Alternate Uses Task. The divergent-thinking strategy of mental disassembly identified by Gilhooly et al may be particularly supported by the rotation and scaling of AUT objects that the computerized AUT supports affords. This observation of “interaction-based” cuing suggests an area of research into divergent thinking support systems that could be further explored.

6.5 Bilateral Eye Movement and Human-Computer Interaction

While my research does not suggest any strong conclusions about the ability of bimanual interaction to support increased inter-hemispheric interaction for strong handed users, a related line of research could investigate the potential of computer interfaces specifically designed to support phenomena already

known to boost IHI, such as bilateral eye movement. The BEM exercise administered by Shobe et al required participants to place their heads in a brace and watch a dot which appeared on opposite sides of a computer monitor repeatedly for 30 seconds. Given that the BEM exercise administered in Shobe et al's research was computer-based, interaction patterns that explicitly guide users through BEM exercises would not be difficult to implement. These BEM-based interfaces could facilitate further confirmatory research in to Shobe et al's findings as well as suggest new approaches to computer-supported creativity systems.

6.6 Design Implications

As is traditional in HCI research, I express here some thoughts on the implications of my research findings for designing creativity support interfaces and multitouch systems. The biggest implication of my research is that I can't really say anything definitive about bimanual influence on divergent thinking other than it matters less than age and language proficiency among a general west-coast university population. (I went fishing for really big effects and didn't get a bite :0) I still believe that it is possible relationships between divergent thinking support and hand use in computer interfaces exist, but a great deal of tightly controlled incremental research is most likely needed to clearly identify these relationships. Given the opportunity and resources to continue my research along these lines, I would repeat the study reported here with a participant group closely screened for consistent spoken English fluency and limited to a smaller age range. Another possible approach to examining relationships between divergent thinking and human-computer interaction would be to compare AUT scores from participants using a symmetric bimanual interface with participants who perform a bilateral eye movement exercise before using a traditional interface. A third approach might involve participants interacting with bimanual or unimanual interfaces in a mundane computing task followed by a paper-administered AUT.

If a designer's goal is to support user creativity via an interface they are designing I would currently advise them that they would be better served by evaluating their against a validated creativity-support index (like the one from Carroll et al (2009), for example) than by considering bimanual or direct vs. indirect interaction beyond good usability principles and other system design constraints. (Carroll et al 2009 outlines important attributes of creativity-support systems based on the flow research of Mihaly Csikszentmihalyi and creativity vocabulary associations.)

Finally, qualitative observations from my experimental session do suggest that being able to fluidly and quickly manipulate creativity source materials may be an important factor in supporting divergent thinking. The ability to rotate and scale the virtual AUT objects in real-time may support different divergent thinking approaches than the idea of an object cued by a written word. Again, my observations of rotation and scale cuing need to be examined further before any strong claims linking fluidity or manipulability of creativity source materials to increased creativity support can be made.

CHAPTER SEVEN: CONCLUSION

7.1 Overview

In Chapter One I briefly introduced my research topic, noted some important foundational research for framing my research approach, and provided an overview of the rest of this thesis document. In Chapter Two I reviewed research and theoretical knowledge from HCI and cognitive psychology which informs and underlies my research approach while clarifying my research questions. In Chapters Three and Four I describe the framework and methodology for my research study, including a description of research instruments, experimental session protocol, participant demographics, and quantitative analytical approach. In Chapter Five I reported the results of quantitative analysis of data from my experimental sessions as well as some qualitative observations. In Chapter Six I discuss the results of the analysis from

Chapter Five in the context of my original research questions and goals; I also summarize possible interpretations of my quantitative results and briefly suggest some areas of focus for interface designers based on my findings. Finally, in Chapter Seven I summarize my thesis document and finish with some thoughts on the limitations of my research and future directions related research might take.

7.2 Summary of Findings

I carried out a between-participants comparison of divergent thinking performance on a computerized version of the Alternate Uses Task via mouse, unimanual multitouch, and bimanual multitouch interfaces. After transforming data from experimental sessions and carrying out a quantitative analysis, no significant differences in divergent thinking performance can be attributed interface style. However, as strong effect for language background was detected, prompting my recommendation of future interface style and divergent thinking research with more homogeneous participant groups. Qualitative observations from my experimental sessions suggest that the ability to rotate and scale 3d models of Alternate Uses Task objects via the computerized AUT may cue unique divergent thinking responses.

7.3 Limitations

As previously discussed in Chapters Four and Six, I made several assumptions in order to carry out this exploratory research within the time and resource constraints of a Master's thesis. These assumptions combined with the strong language effect among my participant group, severely limit any conclusions about the relationship between hand use in computer interfaces and divergent thinking support.

After consulting with a professional statistician, I also acknowledge the limitations of my quantitative analytical approach. Analysis of my dataset would benefit from the application of contemporary statistical techniques such as analysis of covariance, regression diagnostics, and consideration of confidence intervals. For example, analysis of covariance and regression diagnostics may identify

relationships between degree of handedness and AUT performance by treating handedness as a continuous variable rather than dividing participants into handedness groups along the lines of Shobe et al. Similar statistical techniques could also be used to control for the continuity of FAS verbal fluency scores, possibly revealing AUT score trends corrected for language effects.

7.4 Future Research

To continue the line of inquiry I have embarked upon with this research, establishing equivalency in divergent thinking sensitivity between the traditional paper-administered Alternate Uses Task and the computerized Alternate Uses Task is vital. The possibility that the computerized AUT is somehow less-sensitive to variations in divergent thinking performance than the paper version may account for the lack of evidence supporting Shobe et al's findings from my research. My current direct comparison of my findings and predictions based on Shobe et al's research rests on the assumption that paper AUT and computerized AUT are equally sensitive to divergent thinking performance as measured by the AUT. It would also be interesting to further investigate the effects of representation modality on divergent thinking by comparing performance between paper, computerized, and physical object based versions of the AUT. This investigation could involve a between-participants administration of the traditional AUT, a version of the AUT where physical examples of the AUT objects are provided to participants, and a computerized version of the AUT utilizing 3d models such as the instrument from my study.

Ultimately I still feel that investigating the potential relationship between hand use via computer interfaces and divergent thinking as I have attempted here is worthwhile. Future research along these lines should strive vigorously to recruit a more homogenous participant group (paying extra-special attention to language ability) and by recruiting larger numbers of mixed-handed participants.

Appendices

Appendix A: List of Alternate Use Task objects, including typical uses

Appendix B: Post-session Questionnaire, including Edinburgh Handedness Inventory

Appendix C: Expedited Approval of Ethics Application

Appendix A

List of Alternate Use Task objects, including typical uses

Teapot (training object)	used for storing liquids
Button	used to fasten things
Bar of soap	used for washing
Paper clip	hold papers together
Tire	used on wheel of automobile
Eyeglasses	used to improve vision
Comb	used to fix hair
Paper cup	used to hold liquids
Socks	used to keep feet warm
Shoe	used as footwear
Newspaper	used for reading
Key	used to open a lock
Brick	used as building material
Barrel	used to keep things in
Pencil	used for writing
Table	used to place things on

Appendix B

Post-session Questionnaire, including Edinburgh Handedness Inventory

WebSurvey

<https://websurvey.sfu.ca/cgi-bin/WebObjects/WebSurvey.woa/11/wo/G5...>

Computers and Creativity

- This preview shows all your questions on one page, the actual survey delivery will display one question per page for clarity
- Answer the required questions and click "Submit" to see what the "submitted" questions look like
- Click Edit to change an answer
- Click Close when you are finished previewing

Q1 . Participant Number:

-> : *

Q2 . Age in years:

- 18-21
- 22-25
- 26-29
- 30-50
- 50+

Q3 . Gender:

- Female
- Male

Q4 . Can you speak English fluently?

- Yes
- No

Q5 . Is English your native language?

- Yes
- No

Q6 . Please complete the following statements:

	Rarely	Sometimes	Often	Daily
I use a computer mouse :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I use a multitouch device (like an iPhone) :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I use a computer :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q7 . Please indicate which hand you prefer to use for the following activities. Some of the activities require both hands – in these cases, indicate which hand is used for the part of the activity described in parentheses.

	Left Always	Left Usually	No Preference	Right Usually	Right Always
Writing :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Drawing :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Throwing :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Using Scissors :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Using a Toothbrush :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Using a Knife (without a fork) :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Using a Spoon :	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>

WebSurvey

<https://websurvey.sfu.ca/cgi-bin/WebObjects/WebSurvey.woa/11/wo/G5...>

Using a Broom (upper hand) :

Striking a Match (holding the match) :

Opening a Box (holding the lid) :

©1999-2011 [Simon Fraser University](#)

Session Expires: 2011-07-13 02:26 AM

Appendix C

Expedited Approval of Ethics Application



SIMON FRASER UNIVERSITY
THINKING OF THE WORLD

H. Weinberg, Ph.D.
Director, Office of Research Ethics
Simon Fraser University

8888 University Drive
Multi-Tenant Facility
Burnaby, B.C. Canada, V4A 1S6
778 782 6593



Expedited Approval

Date	File	Approval	Principal Investigator
10 June 2010	[2010s0332]	Approved	Bevans, Allen
Risk	Title		Start
Minimal	The effects of bimanual interaction on divergent thinking		10 June 2010
SFU Status	Department / School	Supervisor	End
Graduate Student	SIAT	Antle, Alissa	10 June 2013

Hello Allen,

Your application has been categorized as 'Minimal Risk' and approved by the Director, Office of Research Ethics in accordance with University Policy r20.01.
(<http://www.sfu.ca/policies/research/r20.01.htm>).

The Research Ethics Board reviews and may amend decisions made independently by the Director, Chair or Deputy Chair at the regular monthly meeting of the Board.

Please acknowledge receipt of this Notification of Status by email to dore@sfu.ca and include the file number as shown above as the first item in the Subject Line.

You should get a letter shortly. Note: All letters are sent to the PI addressed to the Department, School or Faculty for Faculty and Graduate Students. Letters to Undergraduate Students are sent to their Faculty Supervisor.

Good luck with the project,

Hal Weinberg, Ph.D.
Director, Office of Research Ethics.

Hal Weinberg, Ph.D.
Director, Office of Research Ethics



Reference List

- Adamson, R. E. (1952). Functional fixedness as related to problem solving: a repetition of three experiments. *Journal of Experimental Psychology*, 44(4), 288-291.
- Amabile, T. M. (1996). *Creativity in context: update to the social psychology of creativity*. Westview Press.
- Amabile, T. M. (1982). Social psychology of creativity: A consensual assessment technique. *Journal of Personality and Social Psychology*, 43(5), 997-1013.
- Ames, M., & Runco, M. A. (2005). Predicting Entrepreneurship From Ideation and Divergent Thinking. *Creativity and Innovation Management*, 14(3), 311-315.
- Balakrishnan, R., & Hinckley, K. (1999). The role of kinesthetic reference frames in two-handed input performance. *Proceedings of the 12th annual ACM symposium on User interface software and technology* (pp. 171-178). Asheville, North Carolina, United States: ACM.
- Balakrishnan, R., & Hinckley, K. (2000). Symmetric bimanual interaction. *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 33-40). The Hague, The Netherlands: ACM.
- Balakrishnan, R., & Kurtenbach, G. (1999). Exploring bimanual camera control and object manipulation in 3D graphics interfaces. *Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit* (pp. 56-62). Pittsburgh, Pennsylvania, United States: ACM.
- Bier, E. A., Stone, M. C., Pier, K., Buxton, William, & DeRose, T. D. (1993). Toolglass and magic lenses: the see-through interface. *Proceedings of the 20th annual conference on Computer graphics and interactive techniques, SIGGRAPH '93* (pp. 73-80). Anaheim, CA: ACM.
- Buxton, W., & Myers, B. (1986). A study in two-handed input. *SIGCHI Bull.*, 17(4), 321-326.

- Buxton, W. (1995). Human-computer interaction. In R. M. Baecker, J. Grudin, W. Buxton, & S. Greenberg (Eds.), (pp. 494–499). Morgan Kaufmann Publishers Inc.
- Carroll, E. A., Latulipe, C., Fung, R., & Terry, M. (2009). Creativity factor evaluation: towards a standardized survey metric for creativity support. *Proceeding of the seventh ACM conference on Creativity and cognition, C&C '09* (pp. 127–136). New York, NY, USA: ACM.
- Chamorro-Premuzic, T., & Reichenbacher, L. (2008). Effects of personality and threat of evaluation on divergent and convergent thinking. *Journal of Research in Personality, 42*(4), 1095-1101.
- Christensen, P. R., Guilford, J. P., Merrifield, P. R., & Wilson, R. C. (1960). Alternate Uses (Form A). *Beverly Hills, CA: Sheridan Supply.*
- Cropley, D., & Cropley, A. (2000). Fostering Creativity in Engineering Undergraduates. *High Ability Studies, 11*(2), 207-219.
- Dahl, D. W., & Moreau, P. (2002). The Influence and Value of Analogical Thinking during New Product Ideation. *Journal of Marketing Research, 39*(1), 47-60.
- DeLacoste-Utamsing, C., & Holloway, R. (1982). Sexual dimorphism in the human corpus callosum. *Science, 216*(4553), 1431 -1432.
- Dietrich, A., & Kanso, R. (2010). A Review of EEG, ERP, and Neuroimaging Studies of Creativity and Insight. *Psychological Bulletin, 136*(5), 822-848.
- Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal Of Engineering Education, 94*, 103--120.
- Dyne, L., & Saavedra, R. (1996). A naturalistic minority influence experiment: Effects on divergent thinking, conflict and originality in work-groups. *British Journal of Social Psychology, 35*(1), 151-167.

- Farooq, U., Carroll, J. M., & Ganoë, C. H. (2005). Supporting creativity in distributed scientific communities. *Proceedings of the 2005 international ACM SIGGROUP conference on Supporting group work, GROUP '05* (pp. 217–226). Sanibel Island, Florida, USA: ACM.
- Fink, A., & Neubauer, A. C. (2006). EEG alpha oscillations during the performance of verbal creativity tasks: Differential effects of sex and verbal intelligence. *International Journal of Psychophysiology, 62*(1), 46-53.
- Fink, A., Benedek, M., Grabner, R. H., Staudt, B., & Neubauer, A. C. (2007). Creativity meets neuroscience: Experimental tasks for the neuroscientific study of creative thinking. *Methods, 42*(1), 68-76.
- Finke, R. A. (1990). *Creative imagery: discoveries and inventions in visualization*. Routledge.
- Forlines, C., & Balakrishnan, R. (2008). Evaluating tactile feedback and direct vs. indirect stylus input in pointing and crossing selection tasks. *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems* (pp. 1563-1572). Florence, Italy: ACM.
- Gibson, C., Folley, B. S., & Park, S. (2009). Enhanced divergent thinking and creativity in musicians: A behavioral and near-infrared spectroscopy study. *Brain and Cognition, 69*(1), 162-169.
- Gilhooly, K. J., Fioratou, E., Anthony, S. H., & Wynn, V. (2007). Divergent thinking: strategies and executive involvement in generating novel uses for familiar objects. *British Journal of Psychology (London, England: 1953), 98*(Pt 4), 611-625.
- Glazer, E. (2009). Rephrasing the madness and creativity debate: What is the nature of the creativity construct? *Personality and Individual Differences, 46*(8), 755-764.
- Guiard, Y. (1987). Asymmetric Division of Labor in Human Skilled Bimanual Action: The Kinematic Chain as a Model.
- Guilford, J. P. (1967). *The nature of human intelligence*. New York, NY, US: McGraw-Hill.
- Guilford, J. P. (1975). Varieties of Creative Giftedness, Their Measurement and Development.

- Hailpern, J., Hinterbichler, E., Leppert, C., Cook, D., & Bailey, B. P. (2007). TEAM STORM: demonstrating an interaction model for working with multiple ideas during creative group work. *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition, C&C '07* (pp. 193–202). Washington, DC, USA: ACM.
- Han, J. Y. (2005). Low-cost multi-touch sensing through frustrated total internal reflection. *Proceedings of the 18th annual ACM symposium on User interface software and technology, UIST '05* (pp. 115–118). Seattle, WA, USA: ACM.
- Hasenfus, N., & Magaro, P. (1976). Creativity and schizophrenia: an equality of empirical constructs. *The British Journal of Psychiatry, 129*(4), 346 -349.
- Heilman, K. M., Nadeau, S. E., & Beversdorf, D. O. (2003). Creative Innovation: Possible Brain Mechanisms. *Neurocase, 9*(5), 369-379.
- Hinckley, K., Pausch, R., Proffitt, D., & Kassell, N. F. (1998). Two-handed virtual manipulation. *ACM Trans. Comput.-Hum. Interact., 5*(3), 260-302.
- Hinckley, K., Pausch, R., Proffitt, D., Patten, J., & Kassell, N. (1997). Cooperative bimanual action. *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 27-34). Atlanta, Georgia, United States: ACM.
- Jacob, R. J. K. (1996). Human-computer interaction: input devices. *ACM Comput. Surv., 28*(1), 177-179.
- Kabbash, P., Buxton, William, & Sellen, A. (1994). Two-handed input in a compound task. *Proceedings of the SIGCHI conference on Human factors in computing systems: celebrating interdependence* (pp. 417-423). Boston, Massachusetts, United States: ACM.
- Kaufman, J. C., & Beghetto, R. A. (2009). Beyond big and little: The four c model of creativity. *Review of General Psychology, 13*(1), 1-12.
- Keefe, J. A., & Magaro, P. A. (1980). Creativity and schizophrenia: An equivalence of cognitive processing. *Journal of Abnormal Psychology, 89*(3), 390-398.

- Kerne, A., Koh, E., Smith, S., Choi, H., Graeber, R., & Webb, A. (2007). Promoting emergence in information discovery by representing collections with composition. *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition, C&C '07* (pp. 117–126). New York, NY, USA: ACM.
- Kin, K., Agrawala, M., & DeRose, T. (2009). Determining the benefits of direct-touch, bimanual, and multifinger input on a multitouch workstation. *Proceedings of Graphics Interface 2009* (pp. 119-124). Kelowna, British Columbia, Canada: Canadian Information Processing Society.
- Latulipe, C., Kaplan, C. S., & Clarke, C. L. A. (2005). Bimanual and unimanual image alignment: an evaluation of mouse-based techniques. *Proceedings of the 18th annual ACM symposium on User interface software and technology* (pp. 123-131). Seattle, WA, USA: ACM.
- Leganchuk, A., Zhai, S., & Buxton, William. (1998). Manual and cognitive benefits of two-handed input: an experimental study. *ACM Trans. Comput.-Hum. Interact.*, 5(4), 326-359.
- McLaughlin, A. C., Rogers, W. A., & Fisk, A. D. (2009). Using direct and indirect input devices: Attention demands and age-related differences. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 16, 2:1–2:15.
- Moscovich, T., & Hughes, J. F. (2008). Indirect mappings of multi-touch input using one and two hands. *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems* (pp. 1275-1284). Florence, Italy: ACM.
- Mouchiroud, C., & Lubart, T. (2001). Children's original thinking: an empirical examination of alternative measures derived from divergent thinking tasks. *The Journal of Genetic Psychology*, 162(4), 382-401.
- Nichols, C. (2009). Is there an evolutionary advantage of schizophrenia? *Personality and Individual Differences*, 46(8), 832-838.
- Odell, D. L., Davis, R. C., Smith, A., & Wright, P. K. (2004). Toolglasses, marking menus, and hotkeys: a comparison of one and two-handed command selection techniques. *Proceedings of Graphics*

- Interface 2004*, GI '04 (pp. 17–24). London, Ontario, Canada: Canadian Human-Computer Communications Society.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97-113.
- Owen, R., Kurtenbach, G., Fitzmaurice, G., Baudel, T., & Buxton, B. (2005). When it gets more difficult, use both hands: exploring bimanual curve manipulation. *Proceedings of Graphics Interface 2005* (pp. 17-24). Victoria, British Columbia: Canadian Human-Computer Communications Society.
- Plucker, J. A., & Runco, M. A. (1998a). The death of creativity measurement has been greatly exaggerated: Current issues, recent advances, and future directions in creativity assessment. *Roeper Review*, *21*(1), 36.
- Plucker, J. A., & Runco, M. A. (1998b). The Death of Creativity Measurement Has Been Greatly Exaggerated: Current Issues, Recent Advances, and Future Directions in Creativity Assessment. *Roeper Review*, *21*(1), 36-39.
- Pretz, J. E., & Link, J. A. (2008). The Creative Task Creator: A tool for the generation of customized, Web-based creativity tasks. *Behavior Research Methods*, *40*(4), 1129-1133.
- Propper, R. E., Christman, S. D., & Phaneuf, K. A. (2005). A mixed-handed advantage in episodic memory: A possible role of interhemispheric interaction. *Memory & Cognition*, *33*(4), 751-757.
- Razumnikova, O. M. (2004). Gender differences in hemispheric organization during divergent thinking: an EEG investigation in human subjects. *Neuroscience Letters*, *362*(3), 193-195.
- Reese, H. W., Lee, L.-J., Cohen, S. H., & Puckett, J. M. (2001). Effects of intellectual variables, age, and gender on divergent thinking in adulthood. *International Journal of Behavioral Development*, *25*(6), 491.
- Runco, M. A. (1991). *Divergent thinking*. Westport, CT, US: Ablex Publishing.

- Sears, A., & Shneiderman, B. (1991). High precision touchscreens: design strategies and comparisons with a mouse. *International Journal of Man-Machine Studies*, 34(4), 593-613.
- Shneiderman, B. (1982). The future of interactive systems and the emergence of direct manipulation. *Behaviour & Information Technology*, 1(3), 237-256.
- Shneiderman, B. (1997). Direct manipulation for comprehensible, predictable and controllable user interfaces. *Proceedings of the 2nd international conference on Intelligent user interfaces, IUI '97* (pp. 33–39). Orlando, Florida, United States: ACM.
- Shneiderman, B. (2000). Creating creativity: user interfaces for supporting innovation. *ACM Transactions on Computer-Human Interaction*, 7(1), 114-138.
- Shobe, E. R., Ross, N. M., & Fleck, J. I. (2009). Influence of handedness and bilateral eye movements on creativity. *Brain and Cognition*, 71(3), 204-214.
- Silvia, P. J., Martin, C., & Nusbaum, E. C. (2009). A snapshot of creativity: Evaluating a quick and simple method for assessing divergent thinking. *Thinking Skills and Creativity*, 4(2), 79-85.
- Silvia, P. J., Winterstein, B. P., Willse, J. T., Barona, C. M., Cram, J. T., Hess, K. I., Martinez, J. L., et al. (2008). Assessing Creativity With Divergent Thinking Tasks: Exploring the Reliability and Validity of New Subjective Scoring Methods. *Psychology of Aesthetics, Creativity, and the Arts*, 2(2), 68-85.
- Sternberg, R. J. (1988). *The Nature of creativity: contemporary psychological perspectives*. CUP Archive.
- Sternberg, R. J. (1999). *Handbook of creativity*. Cambridge University Press.
- Sternberg, R. J., Kaufman, J. C., & Pretz, J. E. (2002). *The creativity conundrum: a propulsion model of kinds of creative contributions*. Psychology Press.
- Strauss, E., Sherman, E. M. S., & Spreen, O. (2006). *A compendium of neuropsychological tests: administration, norms, and commentary*. Oxford University Press US.

- Tombaugh, T. N., Kozak, J., & Rees, L. (1999). Normative Data Stratified by Age and Education for Two Measures of Verbal Fluency: FAS and Animal Naming. *Archives of Clinical Neuropsychology*, 14(2), 167-177.
- Torrance, E. Paul. (1981). Predicting the Creativity of Elementary School Children (1958-80)--and the Teacher Who "Made a Difference." *Gifted Child Quarterly*, 25(2), 55-62.
- Torrance, E. Paul. (1998). The nature of creativity as manifest in its testing. *The nature of creativity: Contemporary psychological perspectives* (p. 454). New York, NY, USA: Cambridge University Press.
- Torrance, Ellis Paul, Glover, J. A., Ronning, R. R., & Reynolds, C. R. (1989). *Handbook of creativity*. Springer.
- Vercauteren, K., Pleyzier, T., Van Belle, L., Swinnen, S. P., & Wenderoth, N. (2008). Unimanual muscle activation increases interhemispheric inhibition from the active to the resting hemisphere. *Neuroscience Letters*, 445(3), 209-213.
- Verstijnen, I. M., van Leeuwen, C., Goldschmidt, G., Hamel, R., & Hennessey, J. M. (1998). Creative discovery in imagery and perception: Combining is relatively easy, restructuring takes a sketch. *Acta Psychologica*, 99(2), 177-200.
- Warr, A., & O'Neill, E. (2006). The effect of group composition on divergent thinking in an interaction design activity. *Proceedings of the 6th conference on Designing Interactive systems, DIS '06* (pp. 122–131). University Park, PA, USA: ACM.
- Welcome to Surface. (n.d.). . Retrieved July 27, 2011, from <http://www.microsoft.com/surface/en/us/default.aspx>
- Westerhausen, R., Kreuder, F., Sequeira, S. D. S., Walter, C., Woerner, W., Wittling, R. A., Schweiger, E., et al. (2004). Effects of handedness and gender on macro- and microstructure of the corpus

callosum and its subregions: a combined high-resolution and diffusion-tensor MRI study.

Cognitive Brain Research, 21(3), 418-426.

Wigdor, D., Williams, S., Cronin, M., Levy, R., White, K., Mazeev, M., & Benko, H. (2009). Ripples: utilizing per-contact visualizations to improve user interaction with touch displays. *Proceedings of the 22nd annual ACM symposium on User interface software and technology, UIST '09* (pp. 3–12). Victoria, BC, Canada: ACM.

Wyver, S., & Spence, S. (1999). Play and Divergent Problem Solving: Evidence Supporting a Reciprocal Relationship. *Early Education & Development*, 10(4), 419-444.

Xia, X., Irani, P., & Wang, J. (2007). Evaluation of Guiard's theory of bimanual control for navigation and selection. *Proceedings of the 2007 international conference on Ergonomics and health aspects of work with computers* (pp. 368-377). Beijing, China: Springer-Verlag.

Zelevnik, R. C., Forsberg, A. S., & Strauss, P. S. (1997). Two pointer input for 3D interaction. *Proceedings of the 1997 symposium on Interactive 3D graphics* (pp. 115-120). Providence, Rhode Island, United States: ACM.